HAWAIIAN PLANTERS' RECORD

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On the Cover: Germination studies with dry seed.
Foreground: normal 37-1933 seed. Background: dry 37-1933 seed.

THE USE OF GAMMA RADIATION IN THE WEIGHING OF BAGASSE

G. O. BURR, G. E. SLOANE AND G. T. FURMIDGE*

Early in 1954 the possibility of weighing raw sugar and bagasse, using gamma radiation, was investigated with the basic aim of developing a weighing system with the following characteristics:

1. An over-all accuracy of measurement of ±1 per cent.
2. A stability adequate to permit operation for reasonable periods of time without recalibration or adjustment.
3. A relatively maintenance-free operation.

A further restriction stipulated that the measuring system must meet these requirements without using a high-level radiation source. A high-level source would have made it considerably more difficult to safeguard factory personnel from radiation.

Preliminary studies were made at the Kauai bulk sugar warehouse at Nawiliwili. The remainder of the test work was carried out at Ewa factory and at the Experiment Station. During the project, interest shifted from weighing of sugar to weighing of bagasse, so that most of the development work was done using the latter material.

SUMMARY OF RESULTS

1. A successful bagasse weighing system has been developed using two ionization chambers in a null-type circuit. Over-all error of measurement with this system is about ±0.7 per cent of average bagasse flow rate (±0.35 per cent of full scale). It may be possible to reduce this figure further by using an improved method of calibration.
2. A weighing system utilizing only one ionization chamber has also been developed but has not had the extensive testing undergone by the double-chamber system.

CONCLUSIONS

1. It is possible to weigh bagasse on an industrial basis using the gamma absorption principle.
2. A gamma radiation system would have an advantage over a conventional belt weighing unit in that the weighing element has no moving parts, hence is relatively unaffected by fine bagasse and other dust. It would also be somewhat

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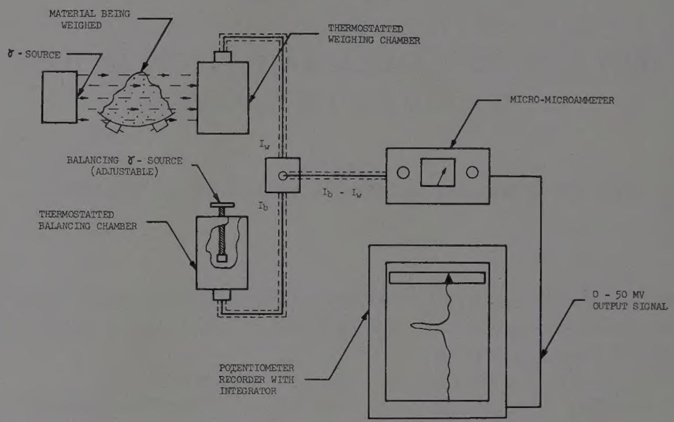
Figure 1

DOUBLE-CHAMBER SYSTEM FOR GAMMA RADIATION WEIGHING



cheaper in most cases as it could be more easily installed on existing bagasse conveyors.

3. Ultimate accuracy of a gamma weighing system may not be as high as that of a belt weigher because the random nature of radioactive emission results in some error. The difference, however, would not be of practical importance in most applications.

4. The system could be used to weigh raw sugar with probably very little modification. It also could be used to weigh chopped or knifed cane, but changes in the physical arrangement of the weighing source and ionization chamber would be necessary.

5. The single chamber system, if it is successful, will be somewhat more flexible in operation as well as less expensive than the double chamber system.

6. With either system it is necessary to carry out a calibration which involves weighing the bagasse and correlating the weights with weigher output.

EQUIPMENT

Double-Chamber Weighing System:

A schematic diagram of the double chamber weighing system is shown in Figure 1. The actual installation operated at Ewa is shown in Figures 2 to 5, and a typical chart record in Figure 6. In Figure 2 are shown the micro-microammeter, 50 millivolt recorder, and integrator counters (mounted on the right side of the instrument stand). The balancing chamber is mounted inside the stand just below the recorder. Figure 3 shows the bagasse conveyor with the radiation source in the box on the left and the ionization (weighing) chamber in the box on the right. Not shown is a steel levelling plate, mounted across the conveyor, which prevents bagasse from piling up above the slats.

Figures 4 and 5 show the weighing and balancing chambers, respectively. The slotted shaft protruding from the end of the balancing chamber is used to adjust the balancing radiation source level.

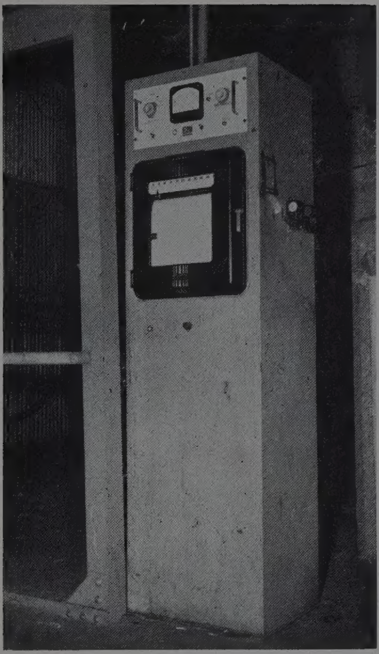


Figure 2. Instrument stand for gamma weigher at Ewa.

The equipment used in the double chamber system is as follows:

Item	Description	
Sources:		
Weighing	Caesium 137	100 millicuries
Balancing	Radium	0.2 millicurie
Ionization Chambers*		
Weighing	Ohmart, Model RTSP, thermostatted	
Balancing	Ohmart, Model RTSN, thermostatted	
Electrometer amplifier	Beckman, Model V-2 Micro-microammeter	
Recorder	Leeds & Northrup, Speedomax	
Integrator (Custom installation)		
Coaxial cable (for ionization chamber connections)	Amphenol, Type 21-467	
Radiation monitor:	Landsverg low-range Pocket Dosimeter Type 25 and Dosimeter charger Type L-20	

The critical items in the above list are Nos. 2, 3 and 6. It would not be advisable to use substitute components in place of these items without prolonged testing for reliability.

The radiation monitor is an optional item. It would be used as a training aid in familiarizing factory personnel with the nature of radiation, and occasionally as a monitor.

Single Chamber Weighing System:

A schematic representation of the single chamber weighing system is shown in Figure 7. Plans are under way to test a factory installation of this type for weighing bagasse. The equipment that will be used is as follows:

* The ionization chamber is a low-output radiation-measuring unit whose output current is directly proportional to radiation intensity.

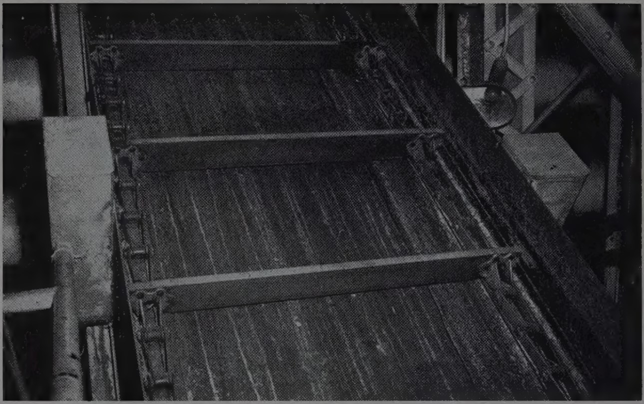


Figure 3. Bagasse conveyor with radiation source and weighing chamber.

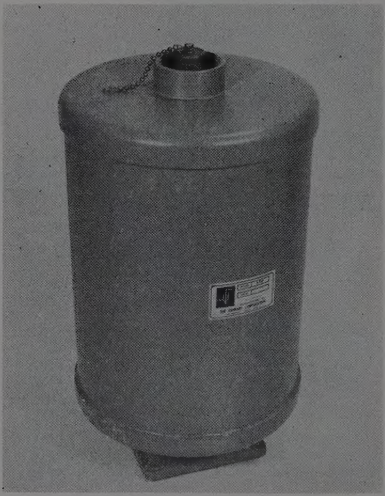


Figure 4. Weighing chamber.

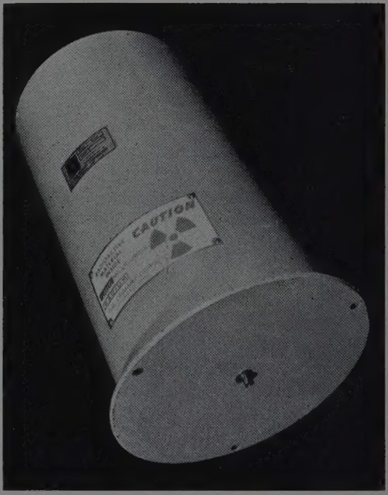


Figure 5. Balancing chamber with built-in source.

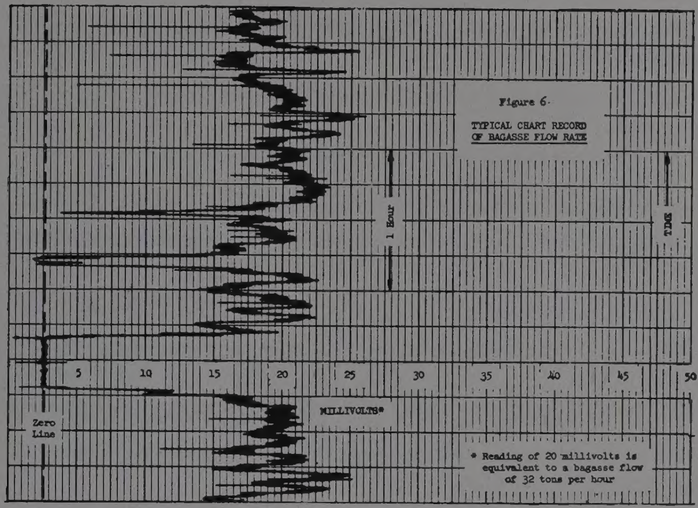
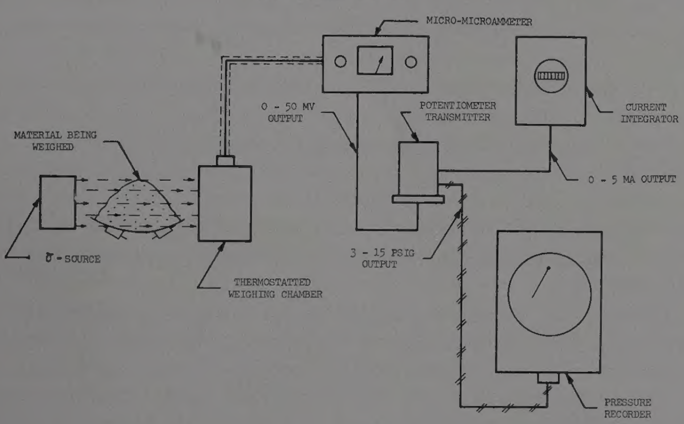


Figure 7

SINGLE-CHAMBER SYSTEM FOR GAMMA RADIATION WEIGHING



Item	Description
Radiation source	Caesium 137 (sealed) 100 millicuries
Weighing chamber	Ohmart, Model RTSN, thermostatted
Electrometer amplifier	Beckman, Model V-2 Micro-Microammeter
Transducer	Taylor, Potentiometer transmitter, Model 700T
Integrator*	Weston Model 808
Recorder	Taylor 3–15 psig
Coaxial cable	Same as for double chamber system
Radiation monitor	Same as for double chamber system

* An air-operated integrator will also be tested.

OPERATION

Basic Principles:

Operation of both the single and double chamber systems is based upon the fact that gamma radiation is absorbed in relation to the mass of the absorbing material (except in those cases where the absorbing material is one of the heavy elements such as lead, gold, etc.). By setting up a system in which the material to be weighed is passed through a beam of gamma rays and by determining the drop in radiation intensity, weight of the material in the beam may be determined once the calibration curve for the system is established. If the material is moving through the beam at a known rate of speed, the mass flow rate of the material may be readily determined (see section on calibration).

The theoretical relationship between mass and per cent absorption is logarithmic, but because of the geometry of the bagasse flow, the actual relationship is essentially linear. This point is discussed in more detail under Linearization of Output.

Difference between Single and Double Chamber Systems:

The percentage of radiation absorption that can be obtained over the width of the average conveyor when weighing a low density material, such as bagasse, is in the order of 25 to 30 per cent. It is highly desirable to amplify this absorption value electrically, otherwise maximum readings on the recorder will never be much over 25 to 30 per cent of full scale. The main difference between the single and double chamber systems is in the way by which each achieves this amplification.

In the double chamber system, the weighing and balancing chambers put out current signals opposite in polarity. The radiation beam is so intense that the current from a single unbalanced ion chamber would throw the recorder off-scale. Hence less than complete absorption of the radiation by the null-point system will give full-scale deflection. For example, if the beam intensity is four times that needed to give full-scale deflection with a single chamber, then a 25 per cent absorption of the radiation by a null-point, double-chamber system, would give full-scale deflection.

By adjusting the current output of the balancing chamber so that for no bagasse flow it is equal to the output of the weighing chamber, a difference signal equal to zero is obtained. As soon as there is bagasse flow, this balance is upset and the output from the balancing chamber predominates. This small difference signal is then amplified sufficiently so that at maximum bagasse flow rates the reading is essentially full scale. The principle of operation is very similar to that of a Wheatstone bridge, in which small variations in a large signal are accurately measured by subtracting a fixed value from it to obtain a small difference signal. This difference is then measured at much higher sensitivities than would have been possible with the original signal.

In the single-chamber system, the fixed or zero portion of the signal is also cancelled out, but the cancellation takes place near the end of the measurement process instead of at the beginning. Without a balancing chamber, the full weighing-chamber output is fed into the micro-microammeter, amplified, and sent to the potentiometer transmitter. In the transmitter, the zero weight portion of the

signal is subtracted from the over-all value, leaving a difference signal*. The difference signal is then further amplified to give full-scale readings at maximum bagasse flow rates.

Calibration Procedure:

It is theoretically possible to calculate the relationship between bagasse flow rate and recorder output level. However, the calculation is so involved and full of uncertainties that it is much better to obtain the relationship empirically.

The calibration method used at Ewa factory involved the following steps:

1. Bagasse flow rate was observed on the recorder until a period of relatively constant flow rate was observed.

2. When the flow rate became reasonably constant, the mill and the bagasse conveyor were stopped and the recorder reading noted.

3. Bagasse was removed from about 25 feet of the conveyor adjacent to the radiation beam, bagged and weighed.

4. The length of conveyor (L) occupied by the weighed bagasse (M) was measured.

5. Values thus obtained for M and L were used with the carrier speed (V) to calculate the mass flow rate (Y_c) using the following equation:

$$Y_c = \frac{M \times V}{L}$$

The process was repeated a number of times at different flow rates, and a least squares correlation between Y_c and recorder reading (X) was developed. The accuracy of the correlation and its linear characteristics are covered under Results and Discussion. An alternative calibration method is also discussed.

RESULTS AND DISCUSSION

Measurement Accuracy

Calibration Results: The calibration curve for the double chamber unit at Ewa is shown in Figure 8. Since each point on the curve was calculated from a 10-second flow of bagasse, the standard error of estimate ($\sigma_{y \cdot x}$) is thus the error in measuring the flow over this same interval. This figure is ± 1.76 tons per hour** which is ± 4.35 per cent of the average bagasse flow (40.5 tons per hour).

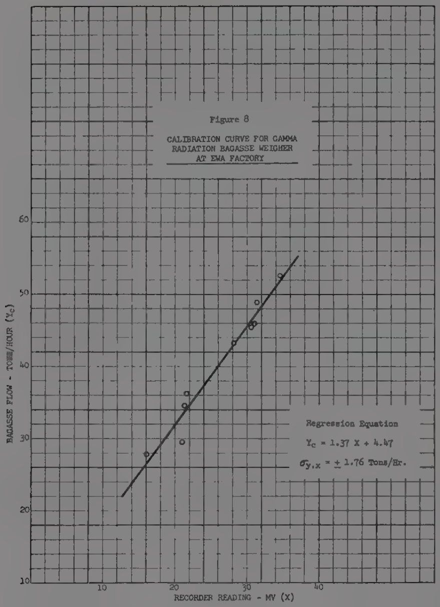
Considered only in terms of a 10-second sample, the accuracy of measurement is not satisfactory. Accuracy obtained, however, in measuring flow over, say, an hour's time, is quite good because the random errors in the 360 10-second measurements (N) making up the hourly figure largely cancel each other out. The error in measurement over an hour's time at average flow rates is calculated as follows:

$$\sigma \text{ hour} = \frac{\sigma_{y \cdot x}}{\sqrt{N}} = \frac{1.76}{\sqrt{360}} = \pm 0.093 \text{ tons per hour}$$

This error is ± 0.23 per cent of the average bagasse flow rate and is, of course, based upon the assumption that the errors are entirely random. Any systematic

* The subtraction in this case is referred to as zero suppression and is accomplished by proper adjustment of the range zero knob on the transmitter.

** Measured values will be within ± 1.76 tons per hour of the true value 68 per cent of the time.



error would not be reduced by taking a large number of readings and could have a considerable effect upon over-all accuracy.

Systematic Errors: In order to determine whether there was enough systematic drift in the system to cause serious errors, the unit was operated for over a month after the end of the 1959 grinding season without being adjusted or disturbed. Over this period, the observed zero point did not vary more than ±1.24 per cent* from the average zero value (Figure 9). During any one week, the average variation was less than half of this, about ±0.46 per cent of average bagasse flow.

The over-all system error is difficult to calculate precisely as some of the drift variation may be random rather than systematic. If it were all random (the best case) the error would be:

$$\sigma \text{ over-all} = \sqrt{(0.23)^2 + (0.46)^2} = \pm 0.52 \text{ per cent of average flow rate}$$

Going to the other extreme (drift is systematic), the maximum over-all error is:

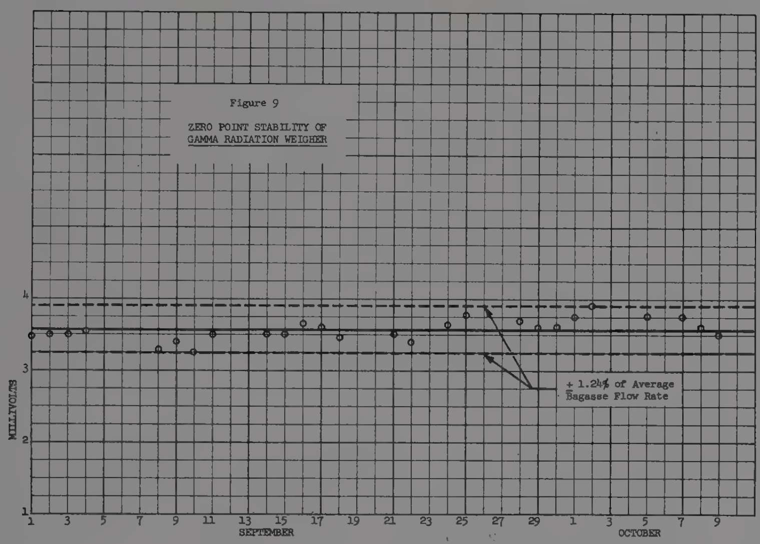
$$\sigma \text{ over-all} = 0.23 + 0.46 = \pm 0.69 \text{ per cent of average flow rate}$$

Taking the worst case, over-all system error is estimated to be about ±0.7 per cent of average bagasse flow rate or about ±0.35 per cent of full scale, if the weighing system zero is reset once a week.

Alternative Method of Calibration

Some of the random error present in the calibration curve in Figure 8 is not

* Per cent of average flow rate. Expressed as a percentage of full scale, the variation would be about one-half of that shown.



due to the system but to the method of calibration that had to be used. Bagasse was collected and weighed just after a reasonably constant recorder output had been observed. It was always difficult to estimate the recorder value exactly, as there was always variation in bagasse flow even under the steadiest operating conditions. It is estimated that the error introduced by this uncertainty in recorder value may be as much as one-half the total error observed.

A different method of calibration can be used which should result in greater accuracy. This involves putting a door on the conveyor bottom at a point where the bagasse can be dumped on the floor or into a tote box. A large quantity of bagasse can then be collected and its weight correlated, using the totalized weight figure rather than the instantaneous rate figure. The accuracy of calibration should be greater because: (1) larger samples of bagasse can be used in making the correlation, (2) a greater number of points can be determined, as it would not be necessary to stop the mill each time a run is made, and (3) the error in estimating instantaneous rates would be eliminated.

This procedure was not used at Ewa because the necessary changes in the conveyor system would have been too expensive. However, in those factories where bagasse can be dumped on the floor from the conveyor at some point after the weigher, the improved procedure should result in greater accuracy of measurement.

Dependability of Components

Searching out and testing system components for reliability was by far the biggest part of the development program. In some cases, it was discovered in a relatively short period of time that a certain piece of equipment would not be suitable for use in a system. In other cases, difficulties arose that took a much longer period of time to develop. This sort of behavior, coupled with the desire to obtain at least one grinding season of successful operating experience with a

complete system, helps to account for the length of time required to develop a suitable unit.

Radiation Sources: There was no reliability problem connected with the radiation sources.

Ionization Chambers: Three ionization chambers were tried out in the weighing system. An air-equivalent ion chamber (General Electric X-Ray/Gamma model) was found to have insufficient output at the desired radioactivity level; the output also varied with atmospheric pressure. Testing of the air-equivalent cell was discontinued after a few months and attention was then concentrated on the Ohmart ionization chamber, Model RT, the only other chamber available at that time.

The Ohmart Model RT ionization chamber had sufficient output, but had to be operated at a constant temperature inasmuch as the output was temperature-sensitive. Attempts to construct a constant temperature enclosure were not wholly successful; the manufacturer later came out with a thermostatted enclosure which satisfactorily solved the problem. It was not possible to use the RT units in the final system, however, as they failed after about a year's service and had to be discarded. Failure resulted from deterioration of the O-ring scale used to retain the ionizing gas in the chambers, and was manifested by a sharp drop in output for a given radiation input. At about this time, the manufacturer came out with an improved cell (Model RTS) in which the joints were sealed by silver soldering. These cells have been in use in the present system for well over a year with no detectable change in output.

Electrometer Amplifiers: Three units, the Brown Electrometer (Minneapolis-Honeywell) and the Beckman Models V and V-2 Micro-Microammeter, were tested. It was not possible to obtain stable operation from the Brown unit and testing was discontinued after a few months. The Beckman units were both found to be highly stable and have given essentially trouble-free operation. The Model V-2, which came out after the Model V, does not have some of the features associated with the Model V, but is suitable for the double chamber weighing system* and is $400 to $500 cheaper.

Recorders: There is no particular reliability problem associated with the choice of a recorder. Any standard industrial recorder with the proper type and range of input would be satisfactory. With the double chamber system, a 0 to 50 millivolt recorder should be used; with the proposed single-chamber system, a 0 to 5 milliampere or 3 to 15 psig recorder could be used.

Connecting Cable: The input circuits in the micro-microammeter are of very high impedance (in the order of 100,000 megohms), so that good cable connections between the ionization chambers and the micro-microammeter are extremely important. Coaxial cables, with insulation resistances in the order of 1×10^{15} ohms or greater, are needed in order to avoid signal losses from the ionization chambers. Amphenol coaxial cable type 21-467 was the only one found that could meet these requirements, although there are undoubtedly other brands that will work.

The importance of having the cable connectors clean cannot be overemphasized. Whenever cables are disconnected for any reason, connector caps should be placed over both the plug and the receptacles to avoid contamination. The insula-

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* It will also be suitable for the single-chamber system if the scale ranges can be modified.

tion surfaces should never be touched with the fingers; doing so will invariably short out the insulation. It is then necessary to thoroughly clean and oven-heat the connector to restore insulation characteristics.

Linearization of Output

The relationship between amount of radiation absorbed and mass is logarithmic, and theoretically a logarithmic scale for the recorder and a logarithmically-cut cam for the totalizer should be used. However, the geometry of the bagasse stream exerts a strong linearizing effect upon the output. In the flow range normally handled, bagasse fills the full width of the slat conveyor at the point where it rests against the slat and then diminishes in width upstream from the slat so that a rounded pile is obtained. The distance along the slat over which this rounding takes place depends upon bagasse flow rates. With low flows the curve is compressed; at high flows it is elongated. The average width occupied by the bagasse is about the same in either case, however, so that the radiation beam passes through approximately the same average width and the same range of widths regardless of flow rates. Thus, percentage absorption by each increment of bagasse is about the same for high and low flow rates.

This point is illustrated in Figure 10, in which conveyor loadings at high and low bagasse rates are shown. The shape of the two absorption curves are approximately the same; the curve for the high flow rates, however, covers a greater percentage of the cycle time. This results in a higher average reading, as shown in a plot of the recorder readings for the high and low flow rates at the right of Figure 10. (The original signal has been filtered to smooth it out.)

The sharp peaks in the unfiltered absorption curves occur when the conveyor slats pass through the radiation beam. These peaks are removed in the filtering process and their contribution to the over-all reading is balanced out by proper zero adjustment.

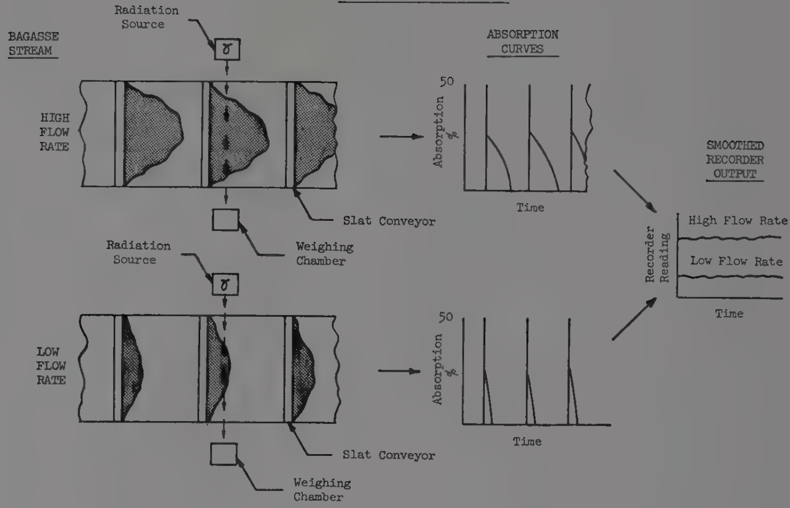
Alternative Weighing Path Arrangements:

Other weighing path arrangements are possible. One alternative arrangement is to use a long source, slightly longer than the width of the conveyor, and to mount it underneath the conveyor at right angles to the direction of motion. The weighing chamber is then mounted a few feet above the conveyor directly over the source. This arrangement does not require a path as long as the one presently in use; hence the radiation intensity does not decrease as much before reaching the weighing chamber. On the other hand, the source traverses only four to five inches of bagasse instead of four or five feet, so that the per cent absorption is considerably less. It is doubtful whether there would be much difference in the weighing accuracy of the two arrangements for any given radiation source level; the method in use was chosen because the radiation source, being smaller, was easier to handle.

Another weighing path that was tried and discarded was the free fall path. The radiation beam was sent through a falling curtain of bagasse coming off the end of the conveyor. This approach was originally considered preferable because the bagasse velocity at any one point in the fall path would be essentially constant. The per cent absorption was too low, however (10 to 13 per cent), to be satisfactory. It was also found that the majority of carriers ran at a constant enough speed to eliminate bagasse velocity as a source of error.

Figure 10

GEOMETRY OF BAGASSE FLOW AND NATURE OF ABSORPTION CURVES THAT ARE OBTAINED



Radiological Safety

The gamma ray source used in the weighing system can be considered low-level as compared to those sources used, for example, in irradiation of plant material. Intensity at the unshielded face of the source box* (facing the carrier) is about 7,000 milliroentgens per hour. Full body exposure to this intensity for 26 minutes would result in the maximum safe dose permitted in any one 13-week period. (Maximum permissible annual dose would result from 43 minutes' exposure.) Radiation intensity falls off rapidly (as the square of the distance) as one moves away from the source, and at distances of three to four feet the radiation level is very low. It is not necessary, therefore, to rope off large areas around the unit in order to safeguard factory personnel.

The unshielded face of the source box can be shielded when repairs are being made on the carrier or adjacent equipment. It is only necessary to put a one-inch lead block over the open face to essentially "shut off" the source.

It is advisable to brief operating personnel as to the nature of the weighing system and the precautions necessary to avoid exposure to radiation. Demonstration of the presence of radioactivity with a radiation monitor is usually very effective in convincing a person not familiar with radiation that there is something there even though he cannot see or feel it.

Atomic Energy Commission regulations require that a sign warning of the presence of radioactive materials be posted in the immediate area. These signs are of a standard design and can be obtained from the Commission.

* This is the maximum intensity to which the individual could expose himself unless he were to open the source box and handle the tube containing the radioactive solution.

ACKNOWLEDGMENT

Work on the gamma weigher project was greatly facilitated by the wholehearted cooperation of the factory staff of Ewa Plantation Company. Special thanks should go to F. R. Wiley, Factory Superintendent, E. F. Ferguson, Mill Engineer, D. C. Jackson, Chief Chemist, and the late G. L. Baker, Shop Superintendent, for their help in making needed facilities and services available, assisting in calibration work, and collecting data during the factory phases of the project.

Acknowledgment is also made of the assistance rendered by G. E. Lambert, Jr., Instrument Technician at the Experiment Station, HSPA. Mr. Lambert helped set up and carry out the early tests made on the weighing system and assisted throughout the project in carrying out system modifications and maintenance.

A SURVEY OF PLANTATION PRACTICES 1949-1959

R. P. HUMBERT*

In 1949, a survey of plantation fertilizer practices for that year's crop was made by Ralph J. Borden, then Agronomist of the Experiment Station, HSPA. Since fertilization practices have changed materially during the last 10 years, a similar survey of the fertilizer practices for the 1959 crop has been made. The differences are large, due to three factors: the use of liquid nitrogen fertilizers; the use of the airplane for supplemental applications of fertilizer on unirrigated plantations; and the high fertilizer requirements of the new cane varieties. It is recognized that the 1958 sugar strike affected fertilization practices for the 1959 crop due to increased age of the crop, but the amount added for the additional months of growing time was partly compensated for by the general lowering of amounts applied in comparison with the peak years of consumption, 1957 and 1958 (Table 1).

TOTAL PLANT FOOD APPLIED

During the last 10 years all plantations have increased their rates of nitrogen fertilization. In 1949, the average nitrogen application was 189 pounds per acre. In 1959, the unirrigated plantations averaged 300 pounds per acre and the irrigated plantations averaged 375 pounds per acre.

All unirrigated plantations use phosphate, with the higher applications on the plant crop. In 1949, 70 per cent of all fields received phosphate, but averaged only 124 pounds P_2O_5 per acre. In 1959, the plant crops received 250 lbs./A on the average, while the ratoons received 175 lbs./A.

Potash applications in 1949, where used, averaged 204 lbs. K_2O/A. In 1959, the unirrigated cane received an average of 400 lbs./A, and the irrigated cane 350 lbs./A.

In 1949, the nitrogen applications ranged from 116 to 252 pounds per acre. Borden (2) reported: "The nitrogen applications appear somewhat high, especially when they are above 200 pounds per acre. Grade A field tests have seldom shown proved gains in sugar for amounts of nitrogen above 175 to 200 pounds per acre even when cane yields were well over 100 tons." Figure 1 shows how the industry average of sugar per acre rose with increased amounts of fertilizer in the period from 1947 to 1957. It is obvious that the newer varieties, combined with cultural practices adapted to their needs, were able to utilize additional plant food to produce more sugar per acre.

* Formerly Principal Agronomist, Experiment Station, HSPA; now Western Director, American Potash Institute, Inc.

Table 1. Fertilizer Purchased for Hawaiian Sugar Industry, 1923–1958

	Nitrogen Purchases in Tons					P_2O_5 Purchases in Tons					K_2O Purchases in Tons				
	Oahu	Hawaii	Kauai	Maui	Total	Oahu	Hawaii	Kauai	Maui	Total	Oahu	Hawaii	Kauai	Maui	Total
1923	2,150	4,134	1,313	1,488	9,085	477	933	1,095	589	3,094	135	1,769	119	121	2,144
1924	2,095	4,470	1,618	1,958	10,141	686	1,049	1,015	509	3,259	459	1,896	245	70	2,670
1925	2,568	4,734	1,775	1,346	10,423	782	1,144	1,321	630	3,877	599	2,334	588	161	3,682
1926	2,740	4,863	2,290	2,085	11,978	1,179	1,271	1,441	881	4,772	1,132	2,698	1,179	330	5,339
1927	2,737	6,227	2,021	2,231	13,216	1,230	1,676	1,621	1,136	5,663	1,185	3,891	1,673	533	7,282
1928	2,824	5,439	2,172	2,512	12,947	1,472	2,012	2,147	1,317	6,948	1,536	4,630	2,162	576	8,904
1929	2,944	5,841	2,427	2,373	13,595	1,595	2,955	2,293	1,190	8,033	1,638	5,442	2,374	766	10,220
1930	2,873	5,809	2,883	2,416	13,981	1,600	3,023	2,502	1,718	8,843	2,132	5,743	2,575	1,177	11,627
1931	2,781	5,768	2,882	2,455	13,886	1,835	3,043	3,014	1,662	9,554	2,073	5,913	2,980	1,252	12,218
1932	2,932	6,411	3,071	2,109	14,523	1,943	4,164	3,018	1,660	10,785	2,288	6,531	2,366	708	11,893
1933	3,195	6,190	3,358	2,799	15,542	2,078	3,701	3,433	1,680	10,892	2,228	6,072	2,527	806	11,633
1934	3,021	6,247	2,792	2,587	14,647	1,686	3,793	2,786	1,420	9,685	1,779	5,659	2,594	438	10,470
1935	2,757	4,857	2,556	2,282	12,452	1,386	2,503	2,733	1,308	7,930	1,581	4,298	1,909	305	8,093
1936	3,412	4,989	2,634	2,595	13,630	1,470	2,633	2,337	1,058	7,498	2,231	4,980	2,298	503	10,012
1937	3,290	5,439	2,485	2,409	13,623	1,593	2,599	1,800	1,160	7,152	2,095	5,671	2,283	508	10,557
1938	3,005	5,198	2,849	2,478	13,530	1,594	1,576	1,617	1,113	5,900	2,122	5,686	2,450	396	10,654
1939	3,098	5,945	2,536	2,513	14,092	1,420	1,924	1,610	941	5,895	2,262	5,713	2,623	521	11,119
1940	2,897	5,221	2,406	2,682	13,014	1,072	1,749	1,401	774	4,976	2,012	6,066	2,461	763	11,030
1941	2,962	5,111	2,487	2,678	13,019	991	2,213	1,095	562	4,861	2,148	5,209	2,375	566	10,112
1942	1,884	4,099	2,263	2,438	10,511	776	1,305	679	478	3,237	973	4,674	1,821	703	8,011
1943	2,456	3,515	2,020	1,935	9,799	803	1,239	576	361	2,979	1,159	4,607	1,643	488	7,774
1944	1,803	2,812	1,678	1,695	7,925	759	888	954	422	4,023	953	3,556	1,645	396	6,489
1945	2,413	4,451	2,918	1,674	11,408	421	1,154	816	204	2,581	1,030	5,174	2,449	238	8,856
1946	1,607	3,182	1,652	1,452	7,893	564	1,094	1,293	241	3,192	1,054	3,719	1,463	310	6,546
1947	1,847	3,940	2,236	2,128	10,151	672	1,690	2,043	265	4,670	1,279	5,052	2,254	405	8,990
1948	2,016	4,281	2,091	2,009	10,397	743	2,225	1,404	241	4,613	1,495	4,984	2,070	489	9,038
1949	1,856	4,238	2,377	2,336	10,807	629	2,347	1,156	532	4,664	1,097	4,139	2,354	430	8,020
1950	2,392	5,316	2,589	2,577	12,874	976	2,062	1,478	924	5,440	1,686	6,540	2,836	568	11,630
1951	2,153	5,367	2,613	2,496	12,629	681	2,819	1,656	691	5,847	2,420	7,018	2,377	640	12,455
1952	2,353	4,870	2,524	2,959	12,865	704	3,322	1,757	681	6,192	2,737	7,165	2,967	768	13,041
1953	2,823	5,860	3,110	2,443	14,236	673	4,263	2,045	609	7,590	2,873	8,112	3,946	883	15,814
1954	2,473	5,582	2,981	3,899	15,489	928	3,602	1,784	459	7,090	2,765	6,984	3,142	1,072	15,248
1955	3,633	6,375	3,626	4,879	18,513	939	3,740	2,182	414	7,275	3,735	7,860	3,826	1,056	16,477
1956	4,024	6,995	3,755	6,202	20,980	1,379	4,018	3,156	813	9,366	4,381	8,983	4,506	1,938	19,808
1957	3,299	7,505	4,008	5,426	20,238	1,251	4,322	3,090	752	9,415	2,981	9,907	4,824	1,651	19,363
1958*	2,154	5,493	2,700	3,234	13,581	732	2,981	2,335	639	6,687	2,045	6,945	3,504	1,032	13,526

* Four-month strike.

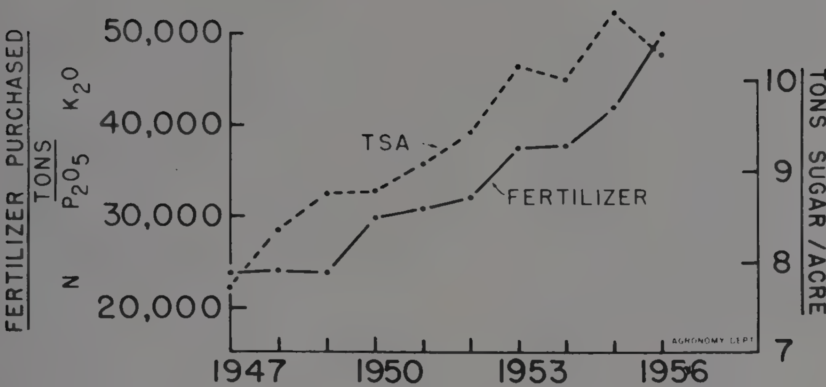


FIGURE 1

METHODS OF APPLICATION

In 1949, all plantations applied some fertilizer on the cane row by hand, an average of three applications being made by this method. Only 13 of the 27 plantations used machines for fertilizer application. Of the 16 plantations practicing irrigation, only eight applied some of their fertilizer in the irrigation water.

In 1959, only a very few plantations applied any fertilizer by hand. Spot fertilization by hand is still practiced on a very limited acreage. Machines, including the airplane, are now in use on all unirrigated plantations (6). Studies of fertilizer applications in general show variable performance records (3). Application of fertilizer by airplane continues to prove as satisfactory as other mechanical means. The distribution of liquid fertilizers by improved equipment geared to the speed of the tractor is proving very satisfactory. All irrigated plantations apply some fertilizer in the irrigation water. Improvements in irrigation layouts are continuously being made to effect a reasonably satisfactory distribution of fertilizer (5).

NUMBER OF APPLICATIONS

In 1949, most of the unirrigated plantations were applying fertilizers in three applications, while four were usually made on the irrigated fields. In 1959, the majority of unirrigated plantations were still using three applications, only a few were using two, while many more were using four, five and six applications. Five applications are commonly used on the irrigated plantations, with three and four applications following in frequency of use (Figure 2).

The present fertilizer practices make sure that adequate fertilizer is applied early in the crop in order to eliminate any chance of deficiencies in the first year's growth, leaving approximately one quarter of the total nitrogen and potash for late first-season or early second-season application, the amount to be based on crop logging and weather experienced in the first season. If unusually good growing weather has occurred, the total will be increased, since extra fertilizer will be applied for a normal second season's growth. If rainy, cloudy weather prevailed

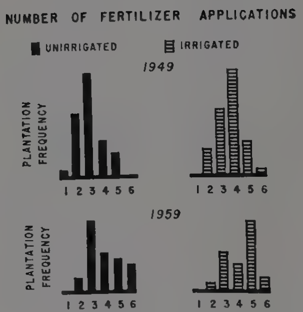


FIGURE 2

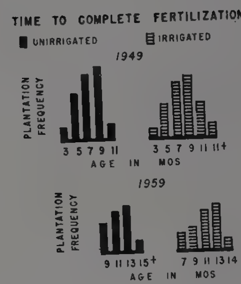


FIGURE 3

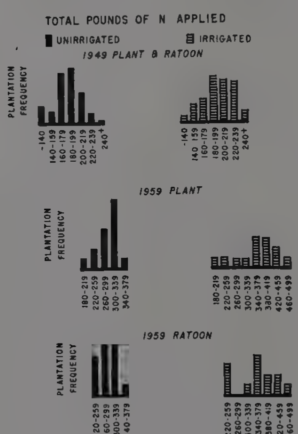


FIGURE 4

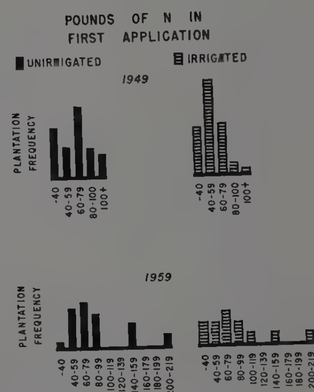


FIGURE 5

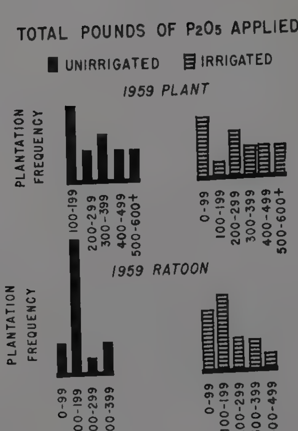


FIGURE 6

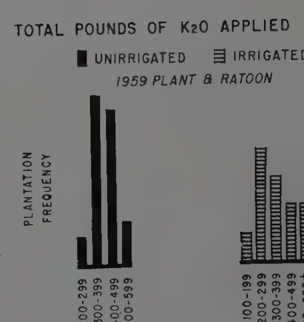


FIGURE 7

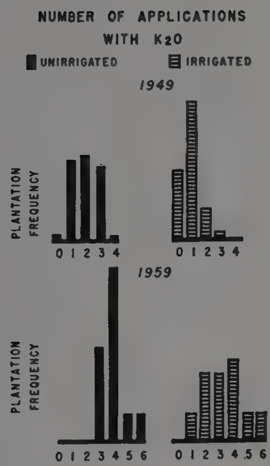


FIGURE 8

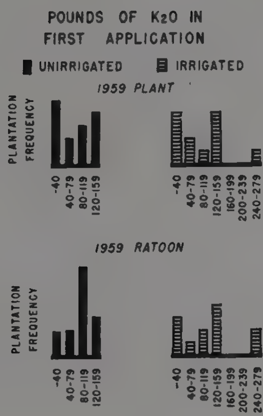


FIGURE 9

during the first season, the total will be subnormal since part of the fertilizer applied for the first season's growth remains in reserve.

COMPLETION TIME FOR FERTILIZATION

The use of the airplane has permitted later applications of fertilizer on the unirrigated plantations than would otherwise be possible. Figure 3 shows that fertilization was completed by seven to nine months in 1949, while it was usually completed by 11 to 13 months in 1959. The time at which fertilization is now completed is similar on both unirrigated and irrigated plantations.

The later applications on a reasonably low base resulted in increased cane tonnage and sugar yields. However, as these applications were made on a continuously rising base, there was a tendency for poorer juice quality at harvest, particularly in those sections of the industry plagued with long periods of cloudy, rainy weather. The timing of the last application on the unirrigated plantations is now generally moved back to the 10- to 12-month period, which still permits an evaluation of the first year's growth and a calculation of a normal second season's requirements.

TOTAL POUNDS OF NITROGEN APPLIED

Applications of nitrogen for cane grown under irrigation were still higher in 1959, just as they were in 1949. Figure 4 shows the considerably higher levels of nitrogen used in 1959 on both irrigated and unirrigated plantations.

There appears to be a wide spread in amounts of nitrogen used on the irrigated plantations. This is partially justified by the wide diversity of climate found in the irrigated districts, ranging from the high sunlight, high growth-potential areas like Ewa, to the cloudy, showery climates of the windward irrigated districts like Kilauea and Kahuku.

POUNDS OF NITROGEN IN FIRST APPLICATION

The majority of plantations still apply reasonably small amounts of nitrogen in the first application, just as they did in 1949. However, several plantations are now injecting high amounts of nitrogen as aqua ammonia with the seed at planting or at ratooning time (Figure 5).

TOTAL POUNDS OF PHOSPHATE APPLIED

Figure 6 shows the frequency of phosphate applications on plant and ratoon crops for 1959. Larger amounts are applied in the plant crop since studies with radioactive phosphate fertilizer showed that the phosphate was used most efficiently when it was placed with the seed at planting time (4). Large amounts of rock phosphate are being broadcast and plowed in to encourage deeper rooting on those plantations where phosphorus-deficient subsoils are being mixed with the shallow surface soils. Detailed root studies by Yamasaki (8) supported the return to this practice commonly used in the middle 1930's.

TOTAL POUNDS OF POTASH APPLIED

Potash consumption has more than doubled since the middle 1940's. Balanced feeding has resulted in the utilization of higher amounts of fertilizer by the newer varieties to produce more cane and sugar (7). Figure 7 shows the frequency of potash usage. The heavier rates are being applied on the unirrigated plantations where the potash reserves in the soil are lower (1).

NUMBER OF APPLICATIONS WITH POTASH

The marked shift to split applications which took place between 1949 and 1959 is shown in Figure 8. Split applications are judged necessary since leaching losses are considered high in the acid soils of the high rainfall districts before the cane's root system is well developed (7). Fewer applications are made in the irrigated plantations, where the soils are only slightly acid to neutral and where leaching losses are considered negligible.

POUNDS OF POTASH IN FIRST APPLICATION

Figure 9 shows that many plantations put on less than 40 pounds K_2O in the first application for plant crops. More potash is usually used in the earlier applications for ratoon crops since losses from leaching seem to be less and rate of early growth is faster.

SUMMARY

The changes in fertilization practices from 1949 to 1959 have been discussed. The higher amounts of fertilizer currently being used are believed to be an important factor in increasing the yield of sugar per acre by two tons throughout the Industry during this period.

LITERATURE CITED

1. Ayres, A. S. and R. P. Humbert, 1957. Single critical levels for soil phosphorus and potassium. Expt. Sta., HSPA Special Release 155.
2. Borden, R. J. 1949–1950. A survey of plantation fertilizer practices. Haw. Plntrs. Rec. 53, pp. 193–198.
3. Hanson, N. S. and R. P. Humbert, 1958. Dry fertilizer application tests at Onomea. Expt. Sta., HSPA Monthly Report, Sept. 1958.
4. Humbert, R. P. 1953. Basic problems of sugar cane nutrition. II. Applying basic factors in sugar cane fertilization. Proc. ISSCT, 8th Cong. pp. 71–79.
5. Humbert, R. P. and A. S. Ayres, 1956. The use of aqua ammonia in the Hawaiian sugar industry. Proc. ISSCT 9th Cong. pp. 524–538.
6. Humbert, R. P. and A. S. Ayres, 1957. The use of aqua ammonia in the Hawaiian sugar industry. II. Injection studies. Soil Sci. Soc. Amer. Proc. 21, No. 3, pp. 312–316.
7. Humbert, R. P. 1958. Potash fertilization in the Hawaiian sugar industry. Symposium, 6th Cong. Int. Potash Inst.
8. Yamasaki, Y. 1956. Root system development under different soil improvement and cultivation practices for the main soil groups. Haw. Sugar Tech. Vol. 15, p. 10.

SPREADING POISONED RAT BAITS BY AIRPLANE

A PROGRESS REPORT

RALPH E. DOTY*

INTRODUCTION

The high cost of labor and the great difficulty of distributing rat bait in some inaccessible cane field and gulch edges have stimulated plantations to develop workable plans by which rat baits could be distributed by airplane. Trials of broadcasting loose grain poisoned with 1080 or thallium sulfate by plane were conducted in the Philippines in 1954 (1) and in California in 1956 (5).

The idea of flying along the gulch edges to scatter rat baits has a tremendous appeal in comparison to the more laborious and slower, but reliable, method of placing bait in long lines of spaced feeding stations. After the general acceptance of distributing fertilizer by airplane, it is merely another step to the acceptance of spreading rat baits by the same means.

Hilo Sugar Company was the first to use the airplane for rat control by purchasing the basic materials necessary for small field trials with pellets, and the Experiment Station, HSPA, agreed to carry on the necessary research. Since the first trials at Hilo Sugar Company in July 1955, other plantations, notably The Lihue Plantation Company, have become interested in air distribution of poisoned rat baits. Studies are continuing with paper torpedoes and paraffin-coated cereal pellets dropped from the air into rat-infested cane fields and adjacent areas.

LIMITATIONS OF DIRECT POISONING

With the airplane available for easy distribution, the whole problem of direct poisoning by "one shot" poison baits is being re-examined. Air distribution of poisoned baits, whether torpedoes or pellets, has the distinct limitation of all direct poisoning operations, that of developing bait shyness in the surviving population (2). Bait shyness is believed to stem from the fact that many rats begin by nibbling and sampling any newly discovered food (9), and that, therefore, in direct poisoning the bait must be made so desirable that the rats will eat a lethal dose during the first feeding. Anything less allows the rats to recover. When and if hairless rats are found in fields and caught in trapping index studies, there can be no doubt that they have eaten a sublethal dose of thallium sulphate poisoned

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bait and will in all probability be bait shy thereafter. Therefore, if air distribution of direct poison is to be a success, the bait must be attractive and effective.

PELLETS

Since the first trials, reported in August 1955 (3), much progress has been made in the manufacture and distribution of pellets. The density and smoothness of the surfaces of the pellets were increased to prevent excessive penetration of hot paraffin during the coating process. This was accomplished by using imported ground oat groats as the basic cereal ingredient in place of flaked oats, which had been the only material available locally at the time of the first experiment. White flour was replaced by white wheat middlings which, though much cheaper, resulted in a satisfactorily hard pellet. The content of fish meal was increased to build up flavor. Raw sugar was substituted for final molasses which, while attractive to rats, was eliminated because a uniform mix of the molasses in the bait was mechanically impossible without adding excessive amounts of water. The water content was further reduced, resulting in an increase in both hardness and smoothness.

The seventeenth trial resulted in a reasonably satisfactory formula which could be manufactured, handled, coated, and distributed without serious difficulty. Modifications of the formula are continuing to improve the attractiveness of the pellets.

The mixture, Formula #17, adopted for preliminary field studies, was made up of the following:

	Ground oat groats		60 lbs.
	White wheat middlings		24 lbs.
	Raw sugar		12 lbs.
	Fish meal		6 lbs.
			102 lbs.
Plus	Thallium sulphate (1-170)	280 grams	
	Paranitrophenol (.003)	139 grams	
	Salt (⅔ lb.)	302 grams	
		721 grams	1.6 lbs.
	Total dry ingredients		103.6 lbs.
	Water (2,050 cc.)		4.5 lbs.

The ingredients were placed, one at a time in the order given, in a fiber drum on a scale and weighed, carrying the scale total forward as each item was added. After it had been measured, about half a gallon of the fish meal was poured into a glass jar with a tight screw cap, and set aside to be used later as the diluent of the salt and thallium mixture.

At this point, the operator put on a respirator and rubber gloves. The thallium sulphate, paranitrophenol and salt were weighed out separately. Then portions of the salt allotment were poured into a mortar, similar portions of thallium sulphate and paranitrophenol were added, and the mixture was carefully stirred and blended with a pestle. The granular structure of the salt breaks the fine thallium sulphate powder into minute particles, preventing cohesion and resulting in a completely even mix. Each well-mixed batch of salt, thallium sulphate and paranitrophenol was added to the fish meal in the gallon jar until all had been used. Then the jar was closed and its contents were thoroughly mixed again by shaking and rolling.

All of the other dry ingredients were poured into the mixer. A minute or two after starting the machine, the contents of the gallon jar were poured carefully into the rotary mixer. The mixer was stopped and the plastic cover placed over the top. The mixer was then operated for five to six minutes. While the machine was turning, the necessary water was introduced under 30-pound pressure by a coarse spray nozzle through a small hole in the center of the plastic cover. After another six or seven minutes, the machine was stopped and the cereal mixture poured out, ready for pelleting.

The pelleting equipment was adjusted to cut the extruding cylinders of bait material into pellets of an average length of one-half to one-quarter of an inch. The fines and broken pieces, one-quarter-inch or less in length, were sifted out by a rotary screen with a mesh one-half inch by one inch, and rerun through the pelleting machine. The pellets were poured on fine screen trays and placed in the drying oven for several hours, preferably overnight. The dry pellets were then ready for dipping in paraffin to reduce absorption of moisture.

The problem of making the pellets sufficiently water resistant to be used successfully in a heavy rainfall area, such as Hilo, is only partially solved. Paraffin melted in a water bath continues to be the most practical material for this purpose. Temperatures of 160° to 180° F. give good results.

The poisoned pellets were placed in a wire basket and dipped in the melted paraffin. As the basket of pellets was lowered into the hot paraffin, it was quickly shaken to separate and move all pellets just enough to allow the paraffin to cover all surfaces. About two seconds or less of actual immersion in the paraffin was generally satisfactory. A dip lasting five seconds or more allows the paraffin to penetrate too deeply. The wire basket must be quickly pulled out of the hot paraffin and allowed to drip for approximately one second; then the pellets are cooled on a tray covered with one-half-inch mesh hardware cloth. If this last operation is delayed, the paraffin begins to harden and the pellets stick together in a mass.

One dipping of paraffin was not entirely satisfactory. A second quick dipping greatly improved the quality of the paraffin coating without penetrating too deeply. Ideally, the second dipping should be brief enough to avoid melting the first coat.

Even with two coats, the pellets are not as waterproof as they should be. The sharp edges remaining when each pellet breaks off as it is extruded from the pelleting machine were undesirable, as the melted paraffin formed thinner coats on edges and corners than on smoother flat surfaces. A second dipping definitely improved the coating of these different areas which, if broken, allowed moisture to enter.

The pellets began to deteriorate after a quarter-inch rain, but remained palatable to rats for at least one more night. The pellets also began to disintegrate after a half-inch or more of rain, and probably became ineffective in 24 to 36 hours. Due to the presence of paranitrophenol, they would not mold for some time, but they would start to sour in about 48 hours.

Several waterproofing materials, such as plastics, shellac, and synthetic monoglycerides, have been tested, but none proved superior to two coats of paraffin.

Paraffin imparts no taste or smell to the pellets. To enable field rats to find single pieces of bait scattered at random in a cane field or wasteland, it is essential

to provide an attractant oil in or on the outer layer of paraffin. It has been demonstrated that attractant oils added to the paraffin have a softening effect on the coating. Therefore, the attractant oil should be applied as a spray on the outside of the paraffin just before the bait is dropped or thrown into the field. Another good reason for adding the oil on the outside of the pellet is to reduce damage by insects which chew many holes in the paraffin, especially when corn oil has been mixed into the paraffin coating. Any vegetable oil may be used as the attractant, but research has shown that some rat species exhibit preferences for particular oils* (2).

In previous work (2), raw linseed oil was sometimes found to be more attractive to rats than corn oil, especially in the very wet regions of Hilo, Hawaii, and Hana, Maui. Raw linseed oil has a strong odor and clings to the paraffin very well, making it a suitable first choice for wet areas.

INSECT DAMAGE TO PELLETS

Insects, which found the pellets very attractive when flavored with corn or raw linseed oils, ate holes through the paraffin coating into the pellet. When insecticides were included in the oil-paraffin coating, the insects had time to damage the pellets before the insecticides could take effect. However, when the insecticides were dissolved in the corn or raw linseed oil attractant sprayed on just before the pellets were distributed in the field, insect damage was greatly reduced since the insects were destroyed before they could penetrate the paraffin coating.

Observation tests were conducted with five insecticides, DDT, chlordane, lindane, pyrethrum and benzene hexachloride, to determine which would be the most effective spray on the pellet. All five materials gave better control than the checks which were badly chewed by insects in all cases. Lindane proved most effective, with DDT a close second. Chlordane was apparently less acceptable to the rats, though effective for insects. Pyrethrum extract, due to volatility, was ineffective after about 48 hours. Benzene hexachloride was almost spectacular in its ability to paralyze dozens of "sand hoppers" (*Orchestia platensis*) in a two-inch radius around a treated pellet. Lindane appeared to be the best insecticide tested. A two per cent concentration by weight of lindane in the oil attractant** seemed sufficient to kill the insects attacking the pellets, without being noticeably objectionable to the rats.

TOXICITY AND ACCEPTANCE OF PELLETS

On the basis of previous experience, the poison concentration of the pellets is now set at one pound of thallium sulphate to 170 pounds of dry-mix bait which carries 2,668 milligrams of Tl_2SO_4 per pound or 5.88 milligrams per gram. The minimum lethal dose (MLD) of thallium sulphate has been studied (2) and it is safe to assume that the reliable amount is 30 milligrams of thallium sulphate per 1,000 grams of body weight of rats.

* The four rat species are: Rattus hawaiiensis (Hawaiian), Rattus rattus rattus (Black), Rattus rattus alexandrinus (Alex.) and Rattus norvegicus (Norway).

** Raw linseed oil specific gravity. 93, weighs 7.56 pounds per gallon (3,520.4 gms). Add two per cent lindane = 70.4 gms. per gallon. Lindane dissolves very slowly in raw linseed oil, so that at least 12 hours must be allowed. Frequent stirrings are helpful.

One three-quarter-inch pellet is a minimum lethal dose for one pound of rat. Since there are, on an average, 160 three-quarter-inch pellets per pound, there could be 160 pounds of rats killed per pound of pellets.

In field practice, it is desirable that the rat should eat much more than the minimum lethal dose for his weight in order to be sure that death results in all cases. Sublethal doses would allow recoveries and immediately develop bait shyness in the surviving rat population.

TOXICITY AND ACCEPTANCE OF PELLETS IN CAGE TESTS

Cage tests were conducted in April and May 1955, at the Experiment Station, HSPA. Fifty-one rats were caged, identified by number, and given a measured length of waxed pellets.

The results of this cage test may be summarized as follows (3): Forty-six, or 90.2 per cent of the 51 rats, ate their pellets promptly during the first night after the bait was offered. Two of this group of 46 survived. The reason for this is unknown, but it is possible that a few unpoisoned pellets became mixed with the poisoned ones, or that pieces could have been lost through the cage wire. Of the remaining five rats, two refused to eat their pellets for one night, one rat refused for two nights, one rat refused for three nights, and one refused for six nights. All subsequently died, but every one of them would have been bait shy in the field.

Thus, out of 51 rats, there were seven, or 13.7 per cent, which would have refused the bait and survived under field conditions. From this cage study, it must be concluded that not over 86 per cent of the rats which actually find a pellet before it spoils in the field would be killed.

This cage test indicated that the acceptance of direct poisoned pellets would not be as good in the field as in the feeding stations. The test also showed that this new approach to the problem may actually be economical and practical if it is not used too frequently in the same area.

ACCEPTANCE OF PELLETS BY RATS IN FIELD TESTS

In May 1955, several observation tests were conducted at Hilo Sugar Company in Fields 54, 67, 68, and in Planter's Ponohawai fields. The tests on the border of Field 68 provided the most information, due to the abundance of rats in the panicum grass along the gulch immediately following harvest.

The acceptance of pellets by rats in the field was highly satisfactory even during nights when one-quarter-inch to three-quarter-inch of rain fell. The insecticides, lindane, chlordane or benzene hexachloride, were first used at five per cent in the linseed oil attractant, and did not seriously interfere with acceptance of pellets. Later it was felt that the five per cent addition of any of the insecticides was much stronger than was necessary to inhibit insect attack, and the strength was reduced to two per cent in subsequent tests. Pival was dropped from the study as it was not very active as an insect repellent. Inadvertently, test stations using DDT as a variable were located in an area where rats happened to be scarce, and so no data were obtained.

DISTRIBUTION BY AIRPLANE

Having determined that pellets, when found by a reasonably hungry rat, are accepted and lethal in an estimated 85 per cent of the cases, it is necessary to estimate how many pellets must be scattered at random per acre if each rat in the entire population is, within its normal range of travel, to find a pellet while it is still palatable. It is probable that at any given time there are no more than 25 to 35 rats in an acre of cane bordering an area where damage is quite severe. It is the cumulative effect of small damage by a few rats persisting for a long time without interference that results in severe losses at harvest.

If it is assumed that one pellet should be dropped for every 56 square feet, 780 to 800 pellets per acre, which is about five pounds of pellets, would be required. If 800 pellets are applied to an acre where there are only 30 rats, there would be about 27 pellets dropped for each rat. This would constitute a low ratio of efficiency of under four per cent. If rats were migrating from adjacent waste areas through this strip of heavily treated land to the field borders, then there could well be rats at the rate of 100 per acre in the strip, resulting in the more favorable ratio of 12 per cent.

The timing of the application will depend largely on the weather. There is no point in distributing pellets during very rainy periods; yet showers of one-quarter-inch or less should not delay the work. The field testing at Hilo Sugar Company indicated that, when rats were present, they took the baits rather promptly the first night. A trial run across the Hilo Sugar Company airstrip applied unpoisoned pellets (average 160 per pound) approximately five feet apart, which amounted to roughly 1,750 pellets, or 11 pounds, per acre. This amount should be more than is necessary under most infield conditions, but it might be desirable to lay this heavier band of bait just at the edge of the brush adjoining the cane and inside the edge of big cane.

In trials at Kipapa airstrip at Oahu Sugar Company, flights at an altitude of 75 feet and an air speed of 85 miles per hour gave an effective swath measurement of 70 to 75 feet, plus a 15-foot fringe of lighter application on each side. In a field test at The Lihue Plantation Company, a discharge rate of 25 pounds of pellets per acre over a field of more than 100 acres was considered an extremely heavy application even for edges of cane bordering on gulch areas.

The plane carries approximately 1,000 pounds of pellets. One loading should carry sufficient pellets to treat 100 acres at the rate of 10 pounds per acre, which should be the maximum application for most conditions, indicating that the expense of air poisoning would be relatively low.

PAPER TORPEDOES

From 1918 through 1938, all efforts to destroy rats in Hawaii were based entirely on direct poisoning. The pioneer study made by Pemberton (8) contributed much basic information which proved invaluable to subsequent studies by the writer. The first rat baits used on a large scale were barium carbonate cakes and strychnine-poisoned wheat made into paraffin-dipped paper "torpedoes". Thallium sulphate replaced strychnine in the poisoned wheat torpedoes in 1929. Beginning in 1935, rolled oats (groats) replaced whole wheat in torpedo baits. When the prebaited feeding station method of rat control became a planta-

tion practice in 1937, the extensive use of torpedo baits ceased except in specific or isolated areas where large-scale operations were not practiced. In 1947, Russell Wold developed a double torpedo to supplement the large-scale feeding station operations at The Lihue Plantation Company. He believed that it had desirable prebaiting characteristics which would more than offset the extra çost.

In 1956, Kawamura (7) of The Lihue Plantation Company reported that he had found the double torpedo "particularly useful in small sporadic infestations and where natural obstructions of the environment make it too difficult or costly to use poison stations". As a first-time single application, the double torpedo has proved effective at Lihue Plantation, and according to Kawamura, population indexes have shown very substantial reductions of up to 85 per cent. Rats at Lihue have shown a preference for loose oats packaged into torpedoes over hard paraffin-coated pellets, when both were offered at the same time. Studies are under way to determine if this preference can be overcome by substituting some other attractant for raw linseed oil, or by changing the pellet formula to include more meat products, which would make them more acceptable to the Norway rats (4).

COMPARISON OF PELLETS WITH TORPEDOES

Kawamura (6) conducted a small preference test (Lihue Bait Preference Test No. 5) in and along the field border and waste land of Field 31 Hm, comparing Lihue's double torpedo with the HSPA zinc phosphide pellet. The test consisted of 50 spaced stations, each furnished with 10 torpedoes and 10 pellets placed together on the ground in a small cleared space.

Kawamura reported as follows: "The results showed high acceptance for both types of bait in locations with high rodent population. Ten of the 50 stations showed that both types of bait were entirely taken. The remaining stations showed varying numbers of baits preferred from one to another. Significant preference for the Lihue torpedo was recorded in many stations which offered sufficient baits for a limited rat population. Some preference for the zinc phosphide pellets was noticed for a few stations."

The results of this test favored the Lihue torpedo over the HSPA zinc phosphide pellet by a preference ratio of 1.7 to 1.0. Two other observation tests at Lihue (#1 and #2) indicated preference ratios of 2.94 and 1.36, respectively, for the Lihue torpedo over 1.00 in each case for the HSPA Formula 17 pellet.

These observation tests indicate that when a choice of bait is offered to the rats, largely of the Norway species, they show a definite preference for torpedoes of loose grain over a solid pellet containing Formula 17. However, an interesting observation noted that the HSPA pellets were preferred at some stations near trees and rock walls. It is suspected that the rats present in these stations were Alex. and Blacks, rather than Norways. The pellets made from Formula 17 were rather well accepted in a field application at Hilo Sugar Company. The spot identification of the dead rats found on a grassy infield road at Hilo Sugar Company indicated that all were either Alex. or Blacks. No Norways were found.

It is concluded that pellet Formula 17 is well taken by Alex., Blacks, and Hawaiiensis on Hawaii, but is not well accepted by the Norway cane rat on Kauai.

LITERATURE CITED

1. Crucillo, C. V., F. Q. Otanes, J. L. Morales. 1954. Control of field rats in Cotabato, Philippines (FQO/ga/7/15/54) Bureau of Plant Industry, Manila, P. I.
2. Doty, R. E. 1945. Rat control in Hawaiian sugar cane plantations. Hawaiian Planters' Record, Vol. 49. or Bulletin 55, Agricultural and Chemical Series, Experiment Station, HSPA.
3. Doty, R. E. 1955. Poisoned rat pellets by airplane. Special Release No. 124, Experiment Station, HSPA.
4. Federal Security Agency, Communicable Disease Center, Public Health Service. 1949. Rat-borne disease, prevention and control. Atlanta, Georgia.
5. Howard, W. E., B. L. Kay, J. E. Street, C. F. Walker. 1956. Range rodent control by plane. Cal. Agr. Exp. Sta. Berkeley. Cal. Agriculture, Vol. 10, No. 10, pp. 8–9.
6. Kawamura, M. Dec. 1955. Lihue Plantation Co., Bait preference tests Nos. 1, 2 and 5. Unpublished report, Project File, Experiment Station, HSPA.
7. Kawamura, M. 1956. The Lihue double torpedo for rat control. Hawaiian Sugar Technologists, 15th Annual Meeting Report.
8. Pemberton, C. E. 1925. The field rat in Hawaii and its control. Bulletin 17, Entomological Series, Experiment Station, HSPA.
9. Spencer, H. J. 1938. Hawaiian rat control project, Dec. 1935–June 30, 1938. Hawaii Agricultural Experiment Station and Bureau of Biological Control cooperating.

FERTILIZATION BY AIRCRAFT IN THE HAWAIIAN SUGAR INDUSTRY

R. P. HUMBERT*

The airplane has become an invaluable tool on the sugar-cane plantations of Hawaii, having applied over 20 million pounds of fertilizer yearly since 1956.

Experiments in foliar fertilization were made by the Pineapple Research Institute in 1942; large-scale spraying of urea on pineapples began in 1949. Foliar fertilization studies with sugar cane were initiated in May 1950, and the first field test of air application was installed at Oahu Sugar Company in July 1950. Early in 1951, foliar sprays were tested on the island of Hawaii. Thereafter, foliar fertilization expanded, until by the end of 1952 over 20,000 acres of cane land had been partially fertilized by aircraft.

During this period of expanding usage of foliar sprays of urea, shortages of potassium were commonly observed. Foliar sprays of muriate of potash in water proved effective in correcting the deficiencies, but the low solubility of this material made it impracticable to apply the quantities needed and forced a shift to granular fertilizers. As a result of early tests on Hawaii in 1952, granular NK fertilizers have now replaced foliar sprays.

EARLY HISTORY

The history of agriculture records horticultural practices which coated trunks and branches of fruit trees with various manurial and mineral substances (10). Foliage feeding was practiced on orchards as early as 1916 (9). More recent work by Hamilton and his co-workers (4) showed that nitrogen from urea could be applied to leaves of apple trees without injury to the foliage; there was an increase of nitrogen in the plant following treatment and a marked deepening in the color of the leaves. Fisher and co-workers (3) found that both nitrogen and chlorophyll levels in the leaves of apple trees were increased by foliage sprays of urea. The increase was greater than from treatments applied to the soil at the same time. Tukey and co-workers (14) stress that "foliage feeding" must take into consideration other portions of the plant, such as trunk, branches, and shoots, as well as foliage. In their studies, K_{42} as potassium carbonate was applied in a six-inch band of cotton gauze around dormant branches of bearing apple trees in midwinter, and was detected 24 hours later in both phloem and xylem 18 inches above and below the band application.

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The author gratefully acknowledges the assistance of N. S. Hanson in the fertilizer distribution pattern studies, and the cooperation extended by Murrayair, Ltd., over the period of study.

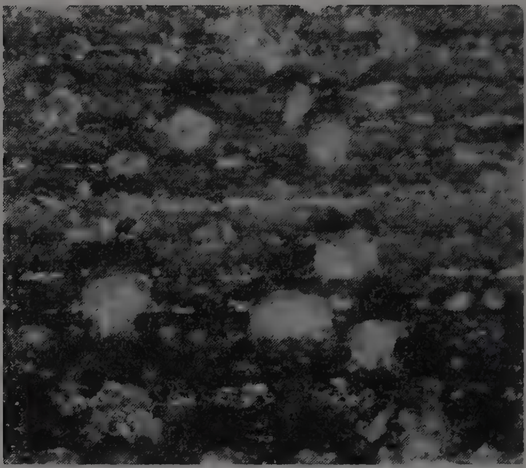

Figure 1. Crystals of urea on a sugar cane leaf dissolving in transpired water (magnification 44×).

The airplane is being widely used in the application of sprays. Literature cites many references to developments in the use of aircraft in agriculture during the last 10 years (2, 12).

The objectives of the experiments in foliar fertilization with sugar cane were to study the entry through the leaves and the translocation of elements essential to plant growth; to define the concentrations of the different fertilizer materials that can safely be applied as a spray; and to compare the efficiency of foliar with soil applications of fertilizer.

METHODS

All of the nitrogen fertilizers commonly used in Hawaii, as well as muriate and sulfate of potash and the water-soluble phosphates, were screened for use as foliar sprays. The more promising, namely urea and muriate of potash, were used in a series of intensive studies.

Staining techniques were used in a microscopic study of the crystallization of urea on the surface of the cane leaves and its subsequent solution and entry into the tissues of the leaf. Burning of leaf tissues was studied in relation to the moisture levels within the cane plant.

The efficiency of fertilizers as foliar sprays was evaluated by means of visual observations, tissue analyses, studies of entry and translocation of radioactive materials, growth measurements, and yield data.

RESULTS

Figure 1 shows urea crystals on the surface of a cane leaf. The smaller crystals are the first to dissolve in the transpired water, with the larger crystals following more gradually. Studies conducted in deep shade, where the stomata were partially closed, showed that much longer time intervals were necessary for solution and entry into the plant. Loss of nitrogen from the leaf surface as ammonia vapor

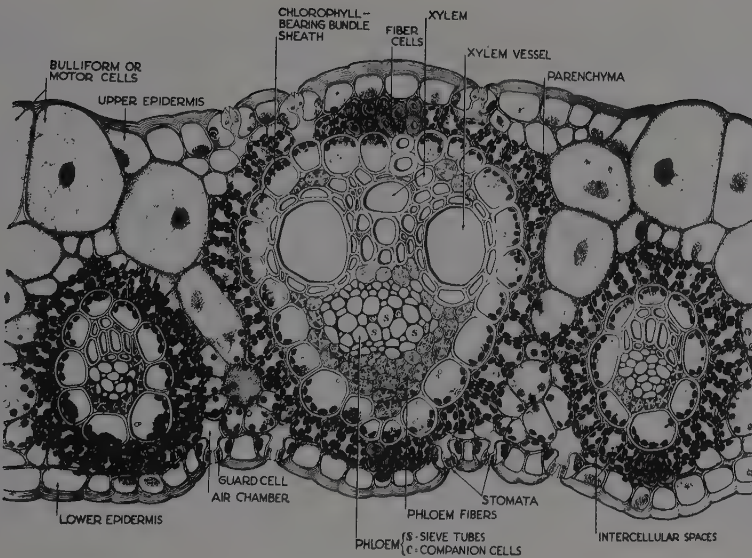

Figure 2. A cross section of an H-109 cane leaf (magnification 274×). After J. P. Martin.

through the action of urease was assumed to be negligible, after the results of Cook and Boynton (1).

Figure 2 shows a cross section of a cane leaf in which there are thousands of stomata per square inch through which entry is possible. In addition to the stomata, the guard and motor cells presumably permitted the entry of small quantities of urea. Approximately 75 to 80 per cent of the urea enters into the plant within a period of 24 to 48 hours; very rapid intake of nitrogen is characteristic in fields of normally growing cane which have been sprayed. Analyses of the growing point after applications show that the N moves into the plant and is translocated to the new tissues. Figure 3 shows typical curves of response to the applications of urea by hand on the soil and as a spray by airplane. It will be noted that the differences between treatments are small after approximately one month, during which three new leaves emerged. Studies with heavy nitrogen (N_{15}) (13) as urea showed that 35 per cent of the sprayed nitrogen remained in the leaves, with the most mobile N in the younger leaves. These results are similar to those of Cook and Boynton (1) which showed that of the amount absorbed by leaves, 84 per cent was still present in the leaves in soluble form after eight hours, 65 per cent after 24 hours, and 43 per cent after 48 hours.

With staining techniques, microscopic examination shows that the urea is transformed to ammonia after entering the plant. The rapid conversion to protein-like compounds in the leaf limits the period of distress caused by the buildup of ammonia. Where distress symptoms are severe and marginal burns occur, the recovery is in most cases rapid. Up to 88 pounds per acre of nitrogen as a saturated solution in water have been put on in a single application with a minimum of leaf burn when precautions were taken to ensure high moisture levels in the cane at the time of application. If the cane is low in moisture at this time, the further

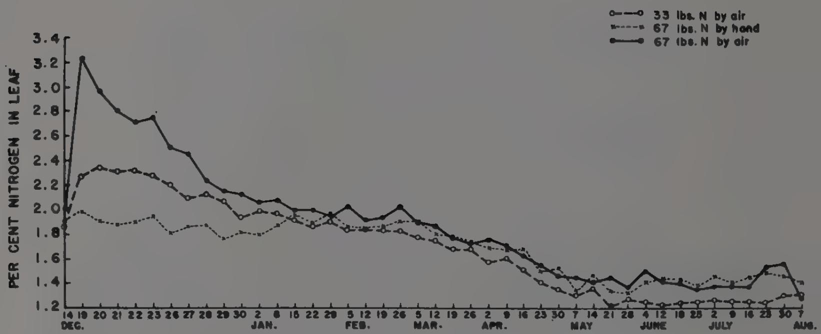

Figure 3. Response to foliar and soil applications of urea, HC&S Company.

dehydration by the urea results in injury to the tissues. No burning results if there is a minimum of 80 per cent moisture in leaf sheaths 3, 4, 5 and 6 at the time of spraying.

Spray pattern studies using fluorescein show that on cane that is closed in, up to 95 per cent of the spray applied falls on the canopy and only five per cent reaches the ground. The rapid entry of urea into the plant is important because of the frequency of rains, particularly on the unirrigated plantations.

Positive response has been generally observed in terms of greener cane which is always associated with higher nitrogen levels. Data in Figure 3 show typical responses in terms of leaf composition.

Growth measurements taken in many tests throughout the industry showed that internode lengths, particularly in the secondaries, were increased by the urea sprayed over the check plots when additional nitrogen was needed for continued growth.

Harvested experiments from several plantations have shown that increased yields of cane and sugar result from supplementary applications of urea. A plant crop of variety 37-1933 harvested at 20.2 months at Wailuku Sugar Company gave significant increases in sugar yields from 25 pounds of nitrogen per acre from urea applied as a spray five and one-half months prior to harvest. The yield data are shown in Table 1.

The data indicate that nitrogen shortages existed during the second season. The nitrogen applied on the foliage late in the crop produced more cane and sugar. No excess nitrogen remained at harvest to impair juice quality. It was encouraging to learn that nitrogen, when needed, could be applied as late as five and one-half months prior to harvest and still be utilized.

Tests harvested at HC&S, Oahu Sugar, McBryde, Lihue, Kohala, the Hilo Coast plantations, Olaa, Hawaiian Ag and Hutchinson supported the rapid ex-

Table 1. Yield Response to Additional Nitrogen by Air at Wailuku Sugar Co.

N Fertilization (lbs/A)						
At Planting	At 14.5 Mos.	Total		TCA	TC/TS	TSA
202	0	202		58.4	7.1	8.2
202	25	227		65.6	7.1	9.2
			LSD	ns	. .	.93

Figure 4. Application of foliar sprays of fertilizer to sugar cane. Rate of application: nitrogen 40 pounds N from urea in 10 gallons of water per acre; potash 19 pounds K_2O from muriate of potash in 10 gallons of water per acre. Height of airplane 35 feet. Swath width 35 feet.

pansion in the use of foliar sprays of urea (5). Shortages of potassium prevented the full utilization of the extra urea applied in the 20,000 acres sprayed before the end of 1952 (Figure 4).

The early tests with muriate of potash in water sprayed on cane gave promising results. This was particularly true in the gray hydromorphic and dark magnesium clay soils where, even with heavy potash fertilization, levels of potassium in the cane were considered below optimum. Cane growing on these soils normally has

Table 2. Response in Sheath K to Foliar Sprays and Soil Applications of Muriate of Potash to Sugar Cane at Kahuku Plantation Co. (Sheaths 3, 4, 5 and 6)

Previous Soil Treatment	Potash Treatment	Before Fertilization % K	1/20/51 % K	2/23/51 % K	5/9/51 % K
20 tons Bagasse	19# K_2O, spray	1.80	2.45	2.60	2.09
	200# K_2O, soil	2.44	2.23	2.58	2.27
Check	19# K_2O, spray	2.23	2.85	2.52	2.49
	200# K_2O, soil	1.95	2.54	2.83	2.62
20 tons Opala	19# K_2O, spray	2.16	2.29	2.49	2.14
	200# K_2O, soil	2.29	2.27	2.45	2.32
15 tons Mudpress	19# K_2O, spray	1.52	2.04	2.29	2.01
	200# K_2O, soil	2.11	2.42	2.44	2.34
Check	19# K_2O, spray	1.91	2.32	2.54	1.95
	200# K_2O, soil	2.37	2.52	2.78	2.36
5 tons Molasses	19# K_2O, spray	2.60	3.12	2.93	2.81
	200# K_2O, soil	2.91	2.97	3.17	2.45

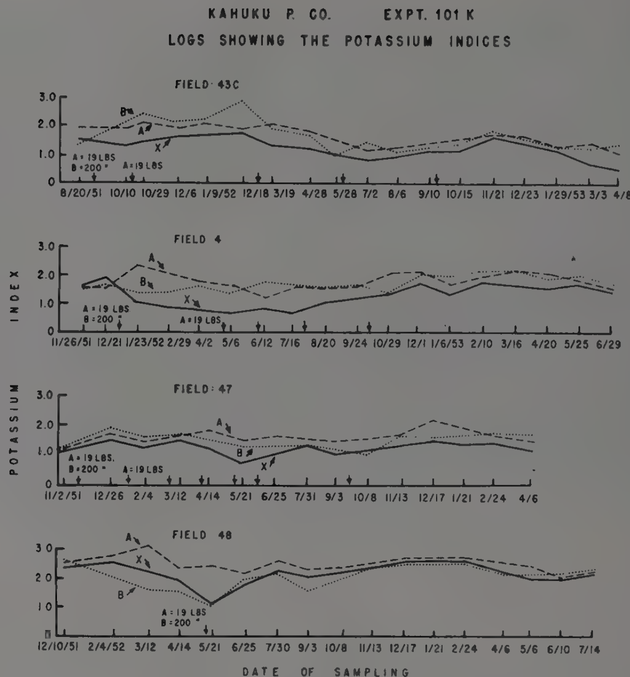

Figure 5. Response to foliar and soil applications of muriate of potash. Foliar applications at the rate of 19 pounds K_2O per acre in 10 gallons of water. Soil applications at the rate of 200 pounds K_2O per acre by hand.

a restricted root system because of the poor physical condition of the soil and the resultant poor drainage and aeration. The soils are in the pH range from 6.5 to 8.0, and part of the deficiency of potassium in the cane plant is attributed to Ca:K antagonism.

Studies with radioactive rubidium, which behaves like potassium, had previously suggested (Experiment Station Annual Report 1952) that potassium is also taken in through the leaves and is translocated to other parts of the plant. The first field studies at Kahuku showed that 19 pounds of K_2O from muriate of potash, which is the amount dissolved in 10 gallons of water to be applied to the cane leaves, was as effective in raising the level of sheath K as 200 pounds of K_2O applied to a gray hydromorphic soil. Table 2 shows the data comparing spray versus soil applications.

Additional tests were installed at Kahuku in fields that showed deficiency levels of potassium on the crop logs. One portion of the field was fertilized with an additional 200 pounds K_2O on the soil, another portion received 19 pounds K_2O by spray every time the leaf sheath potassium fell below 2.0 per cent, and the remainder stayed as plantation practice.

Figure 5 shows the response in terms of leaf sheath potassium for the two treatments in nine fields. The number of sprayings required to keep the sheath

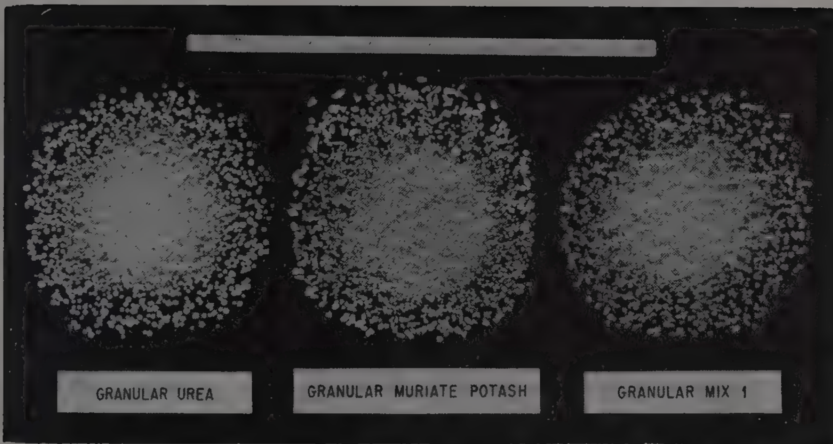

Figure 6. Granular urea, granular muriate of potash, and one of the granular mixes used in aerial applications.

potassium level at or above two per cent varied from one 19-pound treatment in Field 27, where levels were maintained for 12 months, to seven applications in 10 months in Field 23.

Observations made in several of these fields showed that the potassium-deficient cane in the check plots possessed low turgidity, with leaves frayed from blowing in the wind. The leaves in the sprayed plots were turgid and intact units and appeared to be more efficient factories. Reducing the irrigation intervals from a normal 15 days to seven days failed to increase the moisture levels in the cane. Examinations of crop logs throughout the industry show that it is practically impossible to get desirable levels of moisture in the plant when the cane is growing at deficiency levels of potassium.

Potash sprayed at the rate of 19 pounds K_2O per acre on the foliage resulted in composition changes suggesting that several times that amount had entered the cane above ground, and that the foliar spray must have stimulated extraction from the soil. Recent studies by Shereverya (11) and Ikoneko (7) at Kharkov Agricultural Institute, show that the closest inter-relationship exists between foliar and root mineral nutrition in plants. In their studies with wheat, sugar beets and tomatoes, the increase in yield associated with foliar application of nutrients was found to be related to a stimulation by the roots of nutrition in the aerial organs. They suggest that nutrients be applied in small doses, on the basis that this will enhance nutrient flow from the root system. Levin (8) reported that foliar application of potassium exerted a specific effect on oat plants, causing a markedly enhanced root growth. This might account for the increased root activity in our studies with sugar cane.

The high requirements for potash (5), however, and the low solubility of muriate of potash in water, forced the shift from foliar sprays to air application of dry fertilizer.

The American Potash industry developed granular muriate of potash (16) so that it would be compatible with the granular urea (Figure 6). The granular

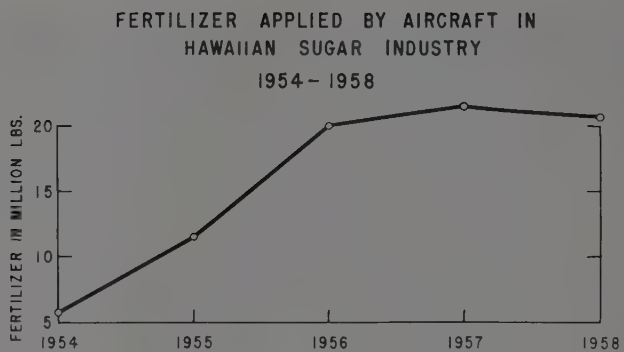

Figure 7. Quantity of fertilizer applied by airplane in the Hawaiian sugar industry. 1954–1958.

mixes have been used in ever-increasing amounts from 1953 to the present (Figure 7), as the second season fertilization resulted in higher yields by prolonging the period of high cane productivity.

Intensive pattern distribution studies, made in cooperation with Murrayair, Ltd., have resulted in modifications to their distributors and a satisfactory distribution of fertilizer (15). In Figure 8, the deflectors which improved the application patterns are shown mounted on the left section of the distributor. The cross sections of the application patterns before and after modification are shown in Figure 9. Prior to the installation of deflector vanes on the slots at the left of the distributor, the propeller slip stream carried an excess of the fertilizer to the left side of the swath. By forcing part of the fertilizer back to the right side, a more uniform application was achieved.

A small percentage of the pellets lodge in the cane at the points where the leaves are attached to the sheaths. With the normal rates of 200 to 300 pounds

Figure 8. Modifications to the seven-slot airplane fertilizer distributor. Note vanes attached as deflectors on the slots at the left to counteract the effects of the propeller slip stream. This development by Murrayair, Ltd. has greatly improved the application pattern.

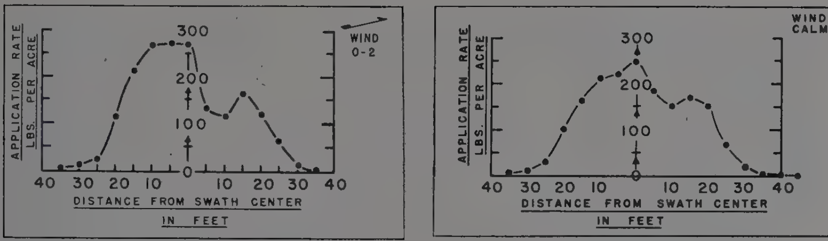

Figure 9. Cross sections of air fertilizer patterns at Olaa Sugar Company before and after modification of the seven-slot distributor on the Stearman plane flying 80 to 85 mph, 25 feet above the cane, applying Granular Mix No. 4. At the left, note heavy application at the left side of the swath, with lower rates on the right side. The deflection of fertilizer to the left was caused by the rotation of the propeller. At the right, the modification of the distributor with vanes in slots 2, 3, 4 and 5, gives a relatively uniform pattern, deflecting part of the fertilizer to the right.

of fertilizer per acre, one to 10 pellets are usually observed in each sheath. Assuming three pellets on the average per leaf sheath, 12 leaves per stalk, and 40,000 stalks per acre during the boom stage of growth, 1,440,000 pellets per acre lodge in the plants. Heavy dews and light rains up to .05 inch dissolve the fertilizer granules without funneling down the stalks. The fertilizer enters through the cane tissues and plays an important role in the early response usually noted. If rains heavier than .05 inch fall, part of the dissolved fertilizer runs down the stalks and enters the soil at the base of the stool just above the zone of maximum concentration of roots. This is an ideal placement and results in a high efficiency of utilization.

The rest of the pellets are well distributed over the soil surface. This broadcast application is made only after the canes' root systems merge in the centers of the interrows. This usually occurs by the time the cane is five to six feet high. Lysimeter studies have shown that leaching losses of nitrogen from aqua ammonia and ammonium sulfate, and of potassium from the muriate, are negligible after effective root systems have been established.

Stalk census studies show that when nitrogen levels in the cane drop, the primary stalks are the first to decrease their rate of growth, followed by the first season secondaries, and finally by the second season suckers. When the yellow-green colors of nitrogen deficiency show up, as they do in the light-colored, check strips in Figure 10, the primary stalks have progressively shorter internode lengths near the small cane tops of seven or eight green leaves, while in the dark-colored strips that received the extra 40 pounds of nitrogen and 60 pounds of K_2O per acre, the internode lengths were maintained at or near the previous rate of growth, and the cane top still consisted of 12 to 13 green leaves—a larger factory to produce more cane and sugar.

As deficiencies of potash become more acute, the lower leaves dry and die prematurely, thus reducing the capacity of the cane top to produce sugar by lowering the number of effective leaves.

The industry's aerial fertilization program continues to expand as accumulated evidence supports heavier fertilization, and particularly adequate plant food for the season's growth. In 13 field experiments testing extra second season fertilization, the average yield increase over the checks was 0.9 ton sugar per acre.

Even though significant increases in sugar yields have resulted from additional

Figure 10. Response to second season application of 40 pounds N per acre and 60 pounds K_2O per acre on the Hilo Coast. Note evenness of color in the treated strips.

fertilizer applied as a liquid on the foliage as late as five and a half months before harvest, it was increasingly evident in the last few crops that juices of poorer quality result from high and late applications of nitrogen. Stalk census studies and plant analyses support the recommendations that the last application of fertilizer be made not later than the fourteenth month of a 24-month crop. Most plantations have made their last application by the time the cane is 12 months of age, which makes it possible to evaluate the growing conditions for the first year and to calculate a normal second season's requirements.

Spot fertilization by airplane is now common practice. Yields of cane and sugar from eroded knolls and other poor areas have for years pulled down field averages. In hilly lands under heavy rainfall, marked color variations from deep green to yellowish-green warn of variable yields at harvest time. Considerable attention has been focused on the benefits of differential fertilization in the past few years. Spot fertilization, or heavier applications to the poor growth areas, has maintained a more uniform color throughout the growing period, and the fields have ripened more uniformly without the extremes of lush-growing cane in the hollows and dead or dying cane on the knolls.

Low phosphorus levels in the cane during the boom stage of growth, following heavy nitrogen and potash fertilization, have awakened interest in N-P-K- granular fertilizers. Five tests harvested to date have shown an average increase of 0.4 ton sugar per acre for the N-P-K fertilizers applied for growth in the late first season and second season.

Air applications of fertilizer are being evaluated on several irrigated plantations where distribution of the fertilizer in irrigation water is known to be variable. The results appear promising.

SUMMARY

Studies which led to the development of an extensive foliar spray program for fertilizer in the early 1950's are reviewed. Twenty thousand acres of cane received part of their nitrogen and potassium requirements as foliar sprays of urea and muriate of potash in water.

The low solubility of muriate of potash in water forced a shift to the use of granular fertilizers. Amounts applied have risen steadily until, in the last three years, annual applications of over 20,000,000 pounds of fertilizer have been made by airplane, largely as late first-season and early second-season supplements on unirrigated plantations. Extensive tests indicate that an average increase of ton sugar per acre has resulted from the supplementary fertilizer applied by airplane.

LITERATURE CITED

Cook, J. A. and D. Boynton. 1952. Some factors affecting the absorption of urea by McIntosh apple leaves. Proc. Am. Soc. Hort. Sci. 59:82–90.

Dobson, S., 1959. Fertilizer takes wings. Better Crops with Plant Food. 43:28–31.

Fisher, E. G. and J. A. Cook. 1950. Nitrogen fertilization of the McIntosh apple with leaf sprays of urea. Proc. Amer. Soc. Hor. Sci., 55:35–40.

Hamilton, J. M., D. H. Palmiter and L. C. Anderson. 1943. Preliminary tests with uramon in foliage sprays as a means of regulating the nitrogen supply of apple trees. Proc. Am. Soc. Hort. Sci., 42:123–126.

Humbert, R. P., 1958. Potash fertilization in the Hawaiian sugar industry. Proc. Sixth Congress Int. Potash Inst., Madrid. (In press).

Humbert, R. P. and N. S. Hanson. 1952. Foliar fertilization of sugar cane by aircraft. HSPA Special Release No. 64.

Ivanenko, T. K., 1959. The interrelationship between root and foliar nutrition and photosynthesis in plants. Plant Physiology (Russian), Vol. 6, No. 1:95–98.

Levin, A. M., 1939. Study of conditions of foliar nutrition of plants with mineral elements and nitrogen. Cand. diss. Kharkov.

Lewis, C. I. and R. W. Allen. 1916. Rpt. 1914–1915 Hood River (Oregon) Branch Expt. Sta., 5.

10 Miller, P., 1754. Gardener's Dictionary.

Sheremeteva, N. I., 1959. The interrelationship of foliar and root mineral nutrition in plants. Plant Physiology (Russian) Vol. 6, No. 1:21–29.

Southwell, P. H., 1951. Application of aircraft to agriculture. World Crops 3:464–468.

Takahashi, D. T., 1959. Six years studies on nitrogen utilization by sugar cane plant using N15 as a tracer. Proc. 10th Congress, ISSCT. (In press).

Tukey, H. B., R. L. Ticknor, O. N. Hinsvark, and S. H. Wittwer. 1952. Absorption of nutrients by stems and branches of woody plants. Sci., Vol. 116. No. 3,007:167–168.

15 USDA, 1957. Now granules can be air-spread evenly. Ag. Res. 6:4.

White, D. P., 1956. Aerial applications of potash fertilizer to coniferous plantations. J. For. 54:762–768.

A SPECTOGRAPHIC STUDY OF THE VARIATIONS IN THE NUTRIENT CONTENT OF SUGAR CANE

T. A. Jones and R. P. Humbert*

Tissue analysis for determining the nutrient status of sugar cane for nitrogen, phosphorus, and potassium, now a routine practice on a majority of plantations in Hawaii, has stimulated interest in the study of other essential elements with the ultimate aim of increasing sugar yields. Since preliminary tissue analyses of these essential elements indicated wide variations, a study was warranted to determine the fluctuations of minor elements throughout the life of the crop.

In the spring of 1954, three varieties were chosen for study on plantations where high yields for these particular varieties were being obtained. The varieties selected were 44-3098 at Hilo Sugar Company, 38-2915 at Laupahoehoe Sugar Company, and 37-1933 at Waialua Agricultural Company. Fields planted in the spring were selected in order to assure ideal growing conditions.

Samples were taken at 3, 6, 9, 12, and 18 months of growth, and at harvest. Each sample consisted of the cane in representative five-foot sections of line. Three five-foot sections from different locations in the field were harvested each time so that samples would be representative of the field. Each sample was divided into leaves, sheaths, mature and immature cane.

SPECTROCHEMICAL ANALYSIS

From 1930 to 1950, the spectrograph at this Experiment Station was used only as a qualitative instrument. It was converted for quantitative analyses in 1950, when the study of the role played by trace elements in sugar cane was intensified.** The method volatilized a homogenized plant ash in a 220-volt DC arc with a current of 9 to 12 amperes. The amounts of the constituents present were estimated by an internal standard and by determining the ratios of certain emission lines of the unknown to the suitable emission spectra of an internal standard. After considerable experimentation, this method was found to lack the reproducible qualities needed. Dr. R. L. Mitchell, of the Macaulay Institute for

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** A Bausch & Lomb large littrow spectrograph with a quartz prism is used. The power excitation is a Bausch & Lomb spark generator, 110 volts, A.C.; secondary potential 15,000 volts, condenser capacity 0.005 mfd.; inductance, 20.56 micro henrys. The film used is Panatomic X cut in the laboratory to fit the film holder. It is developed at 20° C. in Kodak D1 developer for five minutes, followed by an acetic stop bath. It is then placed in Kodak rapid fixer for four minutes, after which it is washed in running water.

Soil Research in Scotland, suggested that the "porous cup technique," developed by Dr. Cyrus Feldman of the Oak Ridge National Laboratory, would be better adapted to the type of samples being analyzed. The method was tried, and has proved reasonably satisfactory.

Porous Cup Technique: The name of this technique derives from the type of electrode used. This electrode is made of graphite, 1½ inches long with a diameter of ¼-inch. The inside hole is ⅛-inch in diameter and is drilled until the floor thickness is .040 inch. This is used as the upper electrode into which a solution of the sample is placed. The bottom electrode is a pointed ¼-inch graphite rod; the analytical gap is approximately 2 mm. As the spark is applied, the sample soaks through the bottom of the porous cup electrode to the sparking surface. The sample, fed by wick action, continuously renews the thin surface film of liquid dispersed by the spark. The sample is sparked for a total of three minutes. It is usually entirely consumed in 2½ minutes; the additional ½ minute ensures complete consumption in all cases.

Photometry

A calibration pattern is impressed on the spectrogram by means of a rotating logarithmic step sector included in the optical bench during sparking. From the geometry of the sector disk, the relative intensity values pertaining to each of the resulting spectra are known. A plate calibration curve is obtained by plotting the galvanometer deflection of the exposure from each of the six steps of the logarithmic step sector against the relative intensity values.

With the DC method of analysis, a logarithmic step sector was used in the optical bench at all times. A full six-log step was photographed for each spectrum line so that a plate calibration curve for the film emulsion was obtained for each element and the internal standard against which it was being compared. A hand-operated densitometer measured the density of each step. This made it extremely difficult to obtain a true background reading that would free the element line from its interfering background.

With the initiating of the porous cup technique came the opportunity to improve the densitometer. By continuing use of the logarithmic step sector to calibrate the film emulsion, the slit height was cut down so that a single step was photographed. A motor drove the densitometer at a constant speed, and instead of using a meter to obtain density peaks, a Leeds & Northrup recorder charted the spectrum lines and their backgrounds. Thus, true density readings and their interfering backgrounds could be accurately obtained.

When new batches of film are used, the logarithmic step sector is inserted in the optical bench with a full vertical slit, and the full six steps of the sector are photographed. Using a number of lines at varying densities, the preceding step densities are plotted against the succeeding step densities on straight graph paper covering a range from 90 to 10. From the resulting curve, an interpolation of the values for the plate calibration curve for the lines and background to be measured can be made from a single reading.

A plate calibration curve is constructed for the internal standard and for its background, as well as for each element and its background. The separation of the internal standard curve and the test element curve, each freed from its respective background, is plotted against the log of concentration of the test elements in the sample; this gives the analytical working curve.

Experimental Results

The results are presented in Table 1. In general, analysis trends are the same, but for the blades and sheaths, immature and mature, the stalk values are lower and the magnitudes of difference are not as great as in the sheath and immature stalk. The immature stalk values are the highest and the differences are of greater magnitude.

Experience has shown that the blade is not reliable for analysis because of the danger of contamination. Even though extreme caution is used in preparing samples, it is virtually impossible to clean all soil particles from the hairs on the blade's surface. When values are low, as in the case of minor elements, contamination is an extremely important problem.

The most significant fact in this study is that, in general, the major and minor elements rise and fall uniformly, and this is coupled with an over-all decrease in

TABLE 1. COMPOSITION OF SUGAR CANE AT DIFFERENT STAGES OF GROWTH

Waialua Agricultural Company, Ltd., Field Kemoo 9. Soil—low humic latosol
Variety: 37-1933 Planted: March Age at harvest: 19 months
Fertilization: N—193 lbs., P_2O_5—193 lbs., K_2O—240 lbs.
Yield: TCA—101.96 TSA—11.3 TC/TS—9.02

Plant parts	Age at sampling	N	P	K	Na	Ca	Mg	Fe	Mn	Cu	Al	B	Ash of dry matter
	(months)	%	%	%	%	%	%	%	%	ppm	ppm	ppm	%
Blade	4	2.19	.20	2.84	...	.51	.23	.048	.031	17	52	7	....
Sheath		1.09	.18	4.54	...	.44	.21	.062	.027	26	44	7	15.99
Immature		...	...	...	...	...	.78	.055	.087	33	39	10	....
Blade	9	1.42	.12	1.66	.126	.53	.39	.028	.019	16	22	6	....
Sheath		.52	.07	2.41	.130	.34	.43	.038	.023	30	28	8	8.67
Immature		1.22	.20	3.93	.158	.45	.66	.070	.024	29	26	26	12.20
Mature		.47	.10	1.17	.049	.11	.32	.064	.009	14	22	23	3.97
Blade	12	1.29	.08	1.53	.050	.56	.31	.020	.016	12	18	6	....
Sheath		.44	.06	2.07	.044	.23	.39	.041	.029	19	15	8	8.25
Immature		.90	.10	1.96	.017	.25	.49	.053	.022	16	20	11	7.02
Mature		.30	.02	.37	.011	.09	.09	.011	.004	6	11	4	1.78
Blade	19	1.16	.11	1.42	.014	.47	.25	.012	.021	8	20	5	6.85
Sheath		.39	.05	2.00	.009	.30	.18	.013	.028	16	13	6	7.50
Immature		.49	.06	1.60	.009	.24	.31	.022	.020	8	15	4	5.32
Mature		.26	.03	.49	.006	.08	.08	.006	.004	4	9	4	2.13

Laupahoehoe Sugar Company, Field H2. Soil—humic latosol
Variety: 38-2915 Planted: May Age at harvest: 24 months
Fertilization: N—308 lbs., P_2O_5—424 lbs., K_2O 469 lbs.
Yield: TCA—85.0 TSA—10.1 TC/TS—8.45

Plant parts	Age at sampling	N	P	K	Na	Ca	Mg	Fe	Mn	Cu	Al	B	Ash of dry matter
	(months)	%	%	%	%	%	%	%	%	ppm	ppm	ppm	%
Blade	4	1.58	.13	2.52	.072	.26	.08	.014	.009	15	9	3	....
Sheath		.55	.05	2.99	.077	.19	.06	.016	.009	28	10	4	7.39
Immature		1.41	.10	3.99	.090	.26	.13	.015	.015	17	7	6	9.34
Blade	7	1.50	.16	2.08	.100	.29	.08	.015	.015	14	9	2	....
Sheath		.53	.06	2.55	.098	.19	.07	.017	.013	27	15	5	7.81
Immature		1.13	.14	5.06	.124	.22	.14	.014	.032	11	7	5	14.22
Mature		.50	.05	1.20	.050	.06	.05	.005	.008	12	6	5	4.24
Blade	10	1.24	.13	2.08	.065	.23	.15	.024	.020	22	22	4	....
Sheath		.56	.05	3.28	.058	.16	.07	.012	.017	21	9	6	9.46
Immature		.85	.09	3.90	.047	.10	.12	.006	.020	13	4	6	10.03
Mature		.37	.05	.99	.030	.05	.07	.008	.011	10	14	4	3.15
Blade	13	1.20	.09	1.84	.037	.20	.05	.027	.015	4	8	3	5.80
Sheath		.46	.04	2.07	.022	.11	.02	.035	.021	21	7	5	6.56
Immature		.67	.14	2.56	.008	.07	.11	.042	.022	10	6	8	6.50
Mature		.26	.02	.43	.009	.04	.01	.012	.006	0.9	4	1	1.51
Blade	20	1.20	.20	1.97	.030	.18	.09	.010	.017	10	26	3	6.01
Sheath		.44	.12	2.37	.024	.09	.07	.060	.019	24	22	4	6.55
Immature		.63	.34	2.62	.015	.06	.20	.046	.023	13	12	3	6.10
Mature		.23	.06	.48	.009	.03	.03	.016	.006	7	6	2	1.54
Blade	24	1.12	.07	1.81	.061	.26	.04	.027	.011	6	7	1	5.64
Sheath		.40	.03	2.02	.047	.16	.02	.038	.017	30	7	1	6.14
Immature		.74	.10	3.18	.038	.14	.11	.039	.021	11	6	3	7.52
Mature		.21	.01	.37	.029	.04	.01	.008	.002	3	4	0.5	1.31

TABLE 1. Concluded

Hilo Sugar Company, Ltd., Field 47. Soil—hydrol humic latosol
Variety: 44-3098 Planted: March Age at harvest: 23 months
Fertilization: N—228 lbs. P_2O_5—460 lbs., K_2O—291 lbs.
Yield: TCA—98.6 TSA—9.2 TC/TS—10.6

Plant parts	Age at sampling	N	P	K	Na	Ca	Mg	Fe	Mn	Cu	Al	B	Ash of dry matter
	(months)	%	%	%	%	%	%	%	%	ppm	ppm	ppm	%
Blade	3	1.86	.11	1.69	...	.39	.26	.026	.004	15	22	--	....
Sheath		1.13	.10	2.91	...	.29	.30	.019	.004	27	16	7	11.64
Immature		1.48	.13	2.73	...	.30	.40	.017	.004	34	15	9	10.93
Blade	6	1.22	.16	1.60	.078	.35	.36	.020	.008	21	17	6	....
Sheath		.40	.07	1.76	.072	.19	.40	.022	.010	31	16	7	8.07
Immature		.36	.05	1.04	.044	.08	.16	.013	.002	13	8	8	3.41
Blade	9	1.33	.10	1.79	.082	.29	.21	.008	.003	14	10	--	--
Sheath		.52	.05	2.22	.078	.20	.23	.016	.005	28	10	4	7.21
Immature		1.02	.09	2.69	.084	.22	.32	.013	.004	17	11	5	8.68
Mature		.32	.03	.51	.027	.06	.14	.007	.002	7	8	--	2.34
Blade	13	1.20	.08	1.57	.018	.31	.24	.005	.001	5	10	6	6.74
Sheath		.50	.05	1.74	.005	.18	.16	.007	.003	8	5	7	7.00
Immature		.69	.11	1.80	.004	.14	.17	.007	.0008	7	5	15	5.48
Mature		.24	.02	.31	.003	.06	.07	.002	.0007	4	4	4	1.62
Blade	18	1.02	.10	1.18	.011	.37	.32	.012	.001	5	17	4	7.31
Sheath		.36	.05	1.42	.011	.16	.21	.015	.004	12	12	4	7.33
Immature		.49	.11	1.71	.017	.13	.15	.012	.0008	6	7	5	5.53
Mature		.12	.03	.22	.007	.05	.05	.004	.0006	3	5	3	1.51
Blade	23	1.03	.09	1.33	.048	.45	.36	.011	.003	4	17	4	9.43
Sheath		.40	.05	1.66	.037	.21	.24	.015	.005	10	13	3	8.57
Immature		.65	.14	1.78	.038	.19	.26	.017	.003	9	11	6	6.50
Mature		.13	.04	.33	.020	.04	.05	.002	.0007	3	12	2	1.67

NOTE: Nitrogen, potassium, calcium and sodium determined chemically. All analyses expressed on dry weight basis.

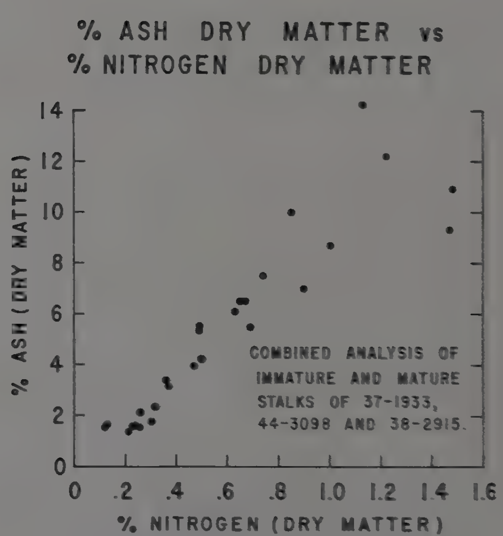

Figure 1.

levels with age. No attempt is made to explain differences in composition due to locations and varieties. The minor elements, in general, are lower on the unirrigated Hilo Coast plantations than at Waialua. Calcium and magnesium are lower at Hilo Sugar and Laupahoehoe, as would be expected, since their soils are more highly leached, with lower pH and lower base saturation. Manganese and iron are also higher at Waialua in all tissues. Spectrochemical analysis of Waialua soils shows them to be very high, particularly in manganese. Aluminum is higher in the Hilo Coast soils, but the plant analyses show higher levels in the Waialua cane. Copper runs about the same for all three plantations, and is generally highest in the sheath. Boron is somewhat higher in the immature stalk and shows comparable levels at the three plantations.

Preparation of samples for spectrographic analysis involves ashing a known dry weight of sample. This ash is weighed and expressed as ash per cent of dry matter. The ash per cent is the best guide to the over-all trends of the levels of all the elements. In the graph, there is a highly significant correlation coefficient of 0.926 when the ash per cent of dry matter (non-volatile mineral constituents) is plotted against nitrogen (Figure 1). As the nitrogen increases, the total ash increases. The scattering of points in the upper range, above one per cent nitrogen, suggests the possibility that this is the range of luxury feeding. In this same range, deficiencies can be easily spotted where total minerals or per cent ash do not increase with increases of nitrogen.

Many analytical methods involve ashing, so that weighing the ash is a common procedure. The incorporation of the ash per cent of dry matter into crop logging procedures, in such a way as to give the over-all non-volatile mineral status of plants, would be a guide and an aid in explaining fluctuations of individual elements.

SUMMARY

This study identified the trace element composition of the three principal commercial varieties grown where they were producing optimum yields. Future comparisons at similar stages of growth should permit interpretations of the adequacy of supply of the various trace elements. There is a strong suggestion that to single out any one particular element at any given time and to assume that it is too low or too high, without information on the other elements, could well give rise to questionable interpretations. This fact should be borne constantly in mind in using plant analysis as a guide to fertilization.

USE OF MILL WASTE ORGANIC MATTER IN IMPROVING HAWAIIAN SUGAR CANE SOILS

G. Y. Ewart and R. P. Humbert*

INTRODUCTION

The advent of mechanical harvesting in the Hawaiian sugar industry resulted in sending large quantities of cane tops, leaves, etc. to the mill. Under rainy harvesting conditions, when the burns are poor, it is not unusual to find 50 per cent extraneous material in the cane hauled to the mill. Huge, expensive cleaning plants were installed to minimize the amount of trash milled with the sugar cane stalks.

Disposal of this trash, together with the bagasse in excess of that needed for fuel, has been costly. Inefficient burning of bagasse in mill furnaces has been practiced to minimize the disposal effort. The Hawaiian sugar industry had made only limited use of these "by-products" as soil amendments prior to the advent of mechanical harvesting because of the satisfactory physical condition of most soils on which cane is grown.

Plantations show wide extremes in climate and soils. The soils with high organic matter content, 15 to 20 per cent, are found in the high rainfall belts. Under rainfall conditions of 100 to 250 inches per year, weathering and leaching have progressed to a stage where the inorganic constituents are comprised largely of hydrated oxides of iron, aluminum and titanium. In the drier regions, the red soils of the uplands are essentially kaolinite clays with varying proportions of the same hydrated oxides. They have relatively low levels of organic matter. The dark-colored, low-lying soils subjected to periodic high water tables are comprised principally of montmorillonite clays with low organic-matter contents.

The nine great soil groups on which sugar cane is grown are described by Cline (1). Figure 1 shows the approximate acreages in each soil group by plantation and by islands. The data were obtained from planimeter measurements of Cline's generalized soil maps of each island with the plantation boundaries drawn in.

The soils rated most likely to respond to additions of organic matter are the gray hydromorphic and dark magnesium clays—soils that need improved permeability and drainage.

Tests with cane trash and bagasse were installed in these soils at Kekaha, Ewa and Kahuku plantations in 1950 and 1951. Application rates varied from five to 60 tons per acre on a dry-weight basis. Detailed studies were made of

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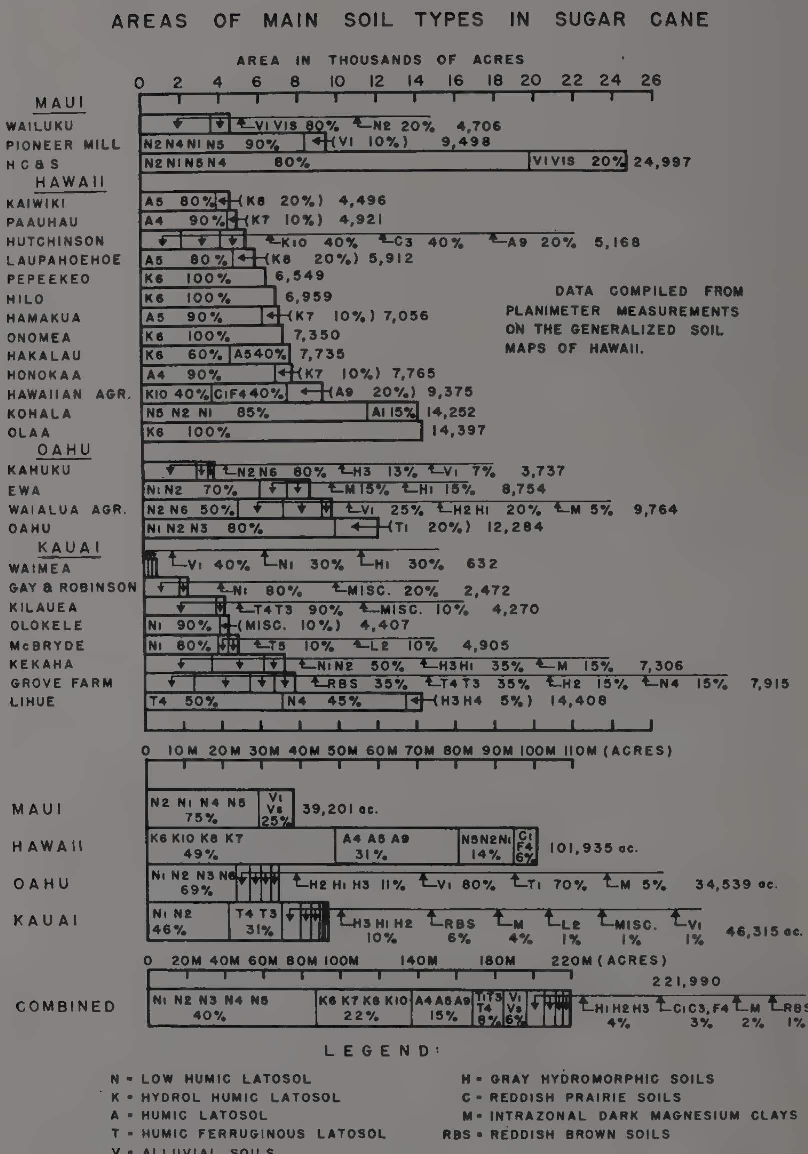

AREAS OF MAIN SOIL TYPES IN SUGAR CANE
AREA IN THOUSANDS OF ACRES
MAUI
WAILUKU
VI VIS 80%
N2 20%
4,706
PIONEER MILL
N2 N4 NI N5 90%
(VI 10%)
9,498
H C & S
N2 NI N5 N4 80%
VI VIS 20%
24,997
HAWAII
KAIWIKI
A5 80%
(K8 20%)
4,496
PAAUHAU
A4 90%
(K7 10%)
4,921
HUTCHINSON
K10 40%
C3 40%
A9 20%
5,168
LAUPAHOEHOE
A5 80%
(K8 20%)
5,912
PEPEEKEO
K6 100%
6,549
HILO
K6 100%
6,959
HAMAKUA
A5 90%
(K7 10%)
7,056
ONOMEA
K6 100%
7,350
HAKALAU
K6 60%
A5 40%
7,735
HONOKAA
A4 90%
(K7 10%)
7,765
HAWAIIAN AGR.
K10 40%
C1 F4 40%
(A9 20%)
9,375
KOHALA
N5 N2 N1 85%
A1 15%
14,252
OLAA
K6 100%
14,397
DATA COMPILED FROM PLANIMETER MEASUREMENTS ON THE GENERALIZED SOIL MAPS OF HAWAII.
OAHU
KAHUKU
N2 N6 80%
H3 13%
V1 7%
3,737
EWA
N1 N2 70%
M 15%
H1 15%
8,754
WAIALUA AGR.
N2 N6 50%
V1 25%
H2 H1 20%
M 5%
9,764
OAHU
N1 N2 N3 80%
(T1 20%)
12,284
KAUAI
WAIMEA
V1 40%
N1 30%
H1 30%
632
GAY & ROBINSON
N1 80%
MISC. 20%
2,472
KILAUEA
T4 T3 90%
MISC. 10%
4,270
OLOKELE
N1 90%
(MISC. 10%)
4,407
McBRYDE
N1 80%
T5 10%
L2 10%
4,905
KEKAHA
N1 N2 50%
H3 H1 35%
M 15%
7,306
GROVE FARM
RBS 35%
T4 T3 35%
H2 15%
N4 15%
7,915
LIHUE
T4 50%
N4 45%
(H3 H4 5%)
14,408
0 10M 20M 30M 40M 50M 60M 70M 80M 90M 100M 110M (ACRES)
MAUI
N2 N1 N4 N5 75%
V1 V5 25%
39,201 ac.
HAWAII
K6 K10 K8 K7 49%
A4 A5 A9 31%
N5 N2 N1 14%
C1 F4 6%
101,935 ac.
OAHU
N1 N2 N3 N6 69%
H2 H1 H3 11%
V1 80%
T1 70%
M 5%
34,539 ac.
KAUAI
N1 N2 46%
T4 T3 31%
H3 H1 H2 10%
RBS 6%
M 4%
L2 1%
MISC. 1%
V1 1%
46,315 ac.
0 20M 40M 60M 80M 100M 140M 180M 220M (ACRES)
221,990
COMBINED
N1 N2 N3 N4 N5 40%
K6 K7 K8 K10 22%
A4 A5 A9 15%
T1 T3 T4 8%
V1 V5 6%
H1 H2 H3 4%
C1 C3, F4 3%
M 2%
RBS 1%
LEGEND:
N = LOW HUMIC LATOSOL
K = HYDROL HUMIC LATOSOL
A = HUMIC LATOSOL
T = HUMIC FERRUGINOUS LATOSOL
V = ALLUVIAL SOILS
H = GRAY HYDROMORPHIC SOILS
C = REDDISH PRAIRIE SOILS
M = INTRAZONAL DARK MAGNESIUM CLAYS
RBS = REDDISH BROWN SOILS

Figure 1

Figure 2. Well-developed root system to the depth of incorporation of 20 tons of bagasse per acre in gray hydromorphic soil at Kahuku Plantation.

infiltration rates, aeration and root development. In the years since 1951, additional experiments have been installed at Olokele, Grove Farm, Lihue, Kilauea, Oahu Sugar, Waialua, Pioneer Mill, Wailuku, Hamakua Mill and Hawaiian Commercial and Sugar companies.

EXPERIMENTAL RESULTS

Yield results from the earlier observation and field scale tests at Kekaha proved the practical value of improving the heavier clay soils with organic matter. Infiltration studies showed that six acre-inches of water took five minutes to seep into gray hydromorphic soil that had received 15 tons of bagasse per acre two and one-half years earlier, while four to five hours were required in the check plots. The root systems in the check plots were restricted to the surface four or five inches of soil, while well developed root systems to depths of 14 to 16 inches were observed in the treated areas. Harvest results showed cane and sugar yields to be in direct proportion to the development of the root system.

The effect of adequate aeration on the development of root systems in the gray hydromorphic soil of Kahuku is seen in Figure 2. The picture was taken in 12-month cane following treatment of 20 tons of bagasse per acre.

The addition of bagasse, with its high carbon to nitrogen ratio of 40 or 50 to 1, results in nitrogen deficiencies early in the crop unless adequate nitrogen fertilization is supplied during the initial stages of decomposition of the bagasse. Trash, composed of cane tops and leaves, with its lower carbon to nitrogen ratio, has given excellent response in terms of improved physical properties of the soil without producing marked symptoms of stress in the cane.

Table 1. Average Yields of Sugar per Acre from Mana Fields Since Start of Improvement Program at Kekaha Sugar Company

Crop	TSA	Acres Harvested
1950	10.69	1,250
1951	11.20	1,150
1952	12.28	1,100
1953	13.30	1,000
1954	13.80	1,200

Field-scale additions of organic materials on gray hydromorphic and dark magnesium clays were first started at Kekaha in the late 1940's. The average yields of sugar per acre from the Mana fields since the start of the soil improvement program are listed in Table 1. During the years 1950 to 1954, soil improvement was the major change in field practice on this plantation (2, 4).

The improvement in physical properties resulted in better internal drainage, which in turn resulted in substantial yield increases. The drains were kept open and free of aquatic weeds by means of aromatic solvents (3) until 1954 when the *tilapia* fish proved that biological control was very effective. The water table has been reduced by approximately three feet as a result of the aquatic weed control program.

Experiments harvested in this same area in 1952 and 1954 show the yield data given in Table 2.

Field yield comparisons before and after soil improvement with mill waste organic matter are listed in Table 3.

An analysis of 23 fields totaling 1,385 acres showed an average gain of 1.4 tons sugar per acre over the last crop prior to treatment, and of .32 TSA over the previous field records.

The second harvest of eight fields totaling 442 acres showed an average gain of 2.09 TSA over the last crop prior to treatment, and of 1.18 TSA over the previous field records.

The third harvest of four fields totaling 316 acres showed an average gain of 3.22 TSA over the last crop prior to treatment, and of 2.05 TSA over the previous field records (Table 4).

The harvest results of Ewa's Experiment 52, testing 15 and 60 tons of trash per acre, are given in Table 5.

Table 2. Observation Tests Yield Results Kekaha Sugar Company

		TCA	TSA
Field 214-2, 1952 crop, pH 7.6	Check Blocks	93.0	13.8
Soil type: Kv, Salinity Medium*	Bagasse (30 T/A)	102.0	14.9
Field 239, 1954 crop, pH 7.8	Check Blocks	62.0	8.5
Soil type: Kv, Salinity High	Bagasse (30 T/A)	81.0	9.6
Field 12, 1954 crop, pH 7.5	Check Blocks	95.0	15.0
Soil type: Lw, Salinity Low	Bagasse (30 T/A)	103.0	16.3

* Salinity Rating: $EC_2 \times 10^6$ = 75 Low
= 75–150 Medium
= 150–275 High
EC_2 = 1:2 soil/water extract conductivity

Table 3. Field Yield Comparisons Before and After Soil Improvement with Mill Waste Organic Matter—Kekaha Sugar Company

Field	Yields Before Treatment Crop	TSA	Yields After Treatment Crop	TSA
214-2	1948	9.8	1952	13.0
	1950	9.6	1954	14.8
236-A	1948	9.7	1952	12.8
	1950	7.5	1954	14.3
237	1948	9.6	1952	12.8
	1950	9.4	1954	15.2
242	1948	8.1	1952	10.2
	1950	7.7	1954	12.8

Table 4. Yields of Mill-Waste Improved Fields at Kekaha Sugar Company

	1st Harvest 1,385.04 Acs. 23 fields		2nd Harvest 442.21 Acs. 8 fields		3rd Harvest 315.97 Acs. 4 fields	
	TSA	TSAM	TSA	TSAM	TSA	TSAM
Improved fields' average yield	12.92	.557	12.96	.536	12.79	.559
Average yields immed. prior to trmt.	11.52	.507	10.87	.453	9.57	.386
Gain	1.40	.050	2.09	.083	3.22	.173
Record crop yields prior to treatment	12.60	.521	11.78	.488	10.74	.461
Gain	.32	.036	1.18	.048	2.05	.098

Table 5. Yield Response to Soil Improvement with Trash at Ewa Sugar Company

Treatment	1952 Plant Crop TCA	Y%C	TSA	1954 1st Ratoon TCA	Y%C	TSA
Check	104.1	14.6	15.1	118.9	14.8	17.5
15 tons trash/Acre	126.1	14.1	17.8	120.1	15.0	19.0
60 tons trash/Acre	114.9	13.0	14.8	133.2	14.3	19.0
LSD	ns	ns	2.2	ns	ns	ns

Table 6. Response to Soil Improvement with Organic Materials

Experiments on Oahu	Treatment	TCA	Y%C	TSA
Oahu Sugar Co. Fd. 27-A	Check	121.4	14.0	16.9
Expt. 178 V × X, 1956 plant crop	31.8 tons compost/A	125.3	13.8	17.3
Low humic latosol	LSD	4.0	ns	ns
Kahuku Fd. 5	Check	77.7	8.4	9.3
Obs. Test, 1952 plant crop	5 tons bagasse/A	86.5	8.3	10.4
Gray hydromorphic	10 tons bagasse/A	76.3	8.4	9.1
	20 tons bagasse/A	71.7	8.3	8.6
No yield data were obtained for	5 tons trash/A	70.8	8.1	8.8
the first ratoon crop. However,	10 tons trash/A	71.5	8.9	8.0
observations showed the	20 tons trash/A	68.7	8.3	8.3
heavier bagasse and trash	LSD	ns	ns	ns
treatments gave the best growth.				
Waialua Fd. Hel. 6C*	Check	101.5	12.6	12.8
Expt. 181 I × OM, 1952 plant crop	10 tons bagasse/A	98.6	12.7	12.2
Low humic latosol	20 tons bagasse/A	97.3	12.6	12.3

* Mulched plots got off to a bad start—were overirrigated, resulting in poor germination, and at 11 months of age the check plots had approximately 25 TCA more than the mulched plots. The mulched plots made up most of this loss in the second-season's growth.

Table 6 Concluded

	Treatment	TCA	Y%C	TSA
Experiments on Kauai				
Olokele Fd. 28	Check	145.3	11.6	16.9
Expt. 18X, 1951 plant crop	20 tons bagasse/A	171.2	11.5	19.6
Low humic latosol	+ extra N			
Kekaha Fd. 12	Check	95.5	15.7	15.0
Expt. 85X, 1954 plant crop	36 tons bagasse +	103.1	15.8	16.3
Dark magnesium clay	130# N			
	Pltn. Prac. + 130# N	102.1	15.6	15.9
	.05% Krilium	105.8	15.3	16.2
	(1,320#/a. :0-8")			
	LSD	ns	ns	ns
Kekaha Fd. 12	Check	97.5	16.7	16.3
Expt. 85X, 1956 1st ratoon	36 tons bagasse +	102.2	16.5	16.9
Dark magnesium clay	130# N			
	Pltn. Prac. + 130# N	99.6	16.1	16.0
	.05% Krilium	99.8	16.4	16.4
	(1,320#/a. :0.8")			
	LSD	ns	ns	ns
Experiments on Maui				
HC&S Fd. 815	Check	91.6	13.1	12.0
Expt. 111, 1956 plant crop	30 tons bagasse/A	124.5	12.7	15.9
Alluvial	60 tons bagasse/A	116.3	12.7	14.8
HC&S Fd. 602	Check	109.7	14.6	16.0
Expt. 107, 1953 plant crop	20 tons bagasse/A	111.9	14.6	16.4
Low humic latosol				
HC&S Fd. 407	Check	93.4	12.1	11.3
Expt. 108, 1953 plant crop	20 tons trash/A	103.3	12.1	12.6
Low humic latosol	20 tons cinders/A	93.5	11.7	11.2
HC&S Fd. 806	Check	118.1	15.1	17.9
Expt. 106. 1953 plant crop	20 tons bagasse/A	115.7	15.0	17.3
Experiments on Hawaii				
Hamakua Fd. 19 RK	Check	105.3	13.1	13.6
Expt. 100 V × X, 1956 plant crop	15 tons compost/A	107.2	13.1	13.9
Humic latosol	LSD	ns	ns	ns
Kohala Fd. Hawi 4	Check	63.3	10.5	6.7
Expt. 165 X, 1953 plant crop	40 tons bagasse/A	67.2	10.5	7.0
Low humic latosol	40 tons trash/A	68.2	10.4	7.1
	LSD	ns	ns	ns
Kohala Fd. Puakea 7	Check	52.6	12.9	6.8
Expt. 171 X, 1952 1st ratoon	45 tons bagasse/A	63.1	12.4	7.8
Low humic latosol	LSD	6.2	ns	.8
Kohala Fd. Puakea 8	Check	61.5	12.7	7.8
Expt. 175 X, 1953 plant crop	30 tons bagasse/A	74.0	12.3	9.1
Low humic latosol	300 lbs. DD	65.5	12.0	7.8
	LSD	8.5	.4	1.0
Kohala Fd. Ainakea 4	Check	97.7	10.0	9.7
Expt. 180 X, 1953 1st ratoon	45 tons bagasse/A	99.0	10.3	10.2
Low humic latosol	Mulch paper	100.1	9.9	10.0
	LSD	ns	ns	ns
Kohala Fd. Union 8	Check	85.2	12.3	10.5
Expt. 187 X, 1953 2nd ratoon	40 tons bagasse/A	92.3	12.2	11.2
Low humic latosol	LSD	ns	ns	.7
Combined study of above	Check	74.7	11.5	8.5
Kohala experiments	30–45 tons bagasse/A	81.3	11.4	9.2
(32 replicates)	LSD	3.1	ns	.3

The plant crop data show a statistically significant 2.7 TSA gain over the checks for the 15 tons per acre treatment. The cane in the 60 tons per acre treatment suffered nitrogen deficiencies in its first year of growth, and did not fully recover the loss in its second-season growth. In the first-ratoon data, however, the 60 tons per acre treatment resulted in the highest yields—19 TSA.

Outstanding improvement in the cane's root system was observed with the trash treatments. A sparsely developed root system with few secondary roots in the six- to 18-inch depth was observed in the checks. The root system of 12-month old plant cane in the 15-ton trash per acre treatment showed a marked increase in volume of roots and the presence of white-tipped, healthy roots with many times the surface area of secondary roots when compared with the checks.

Results from these tests led to the following recommendation which has proved adequate over the last six years. The requirements of the microbiological population during the initial stages of decomposition are adequately met by supplementing normal fertilization with six pounds of nitrogen per ton of organic material. Later applications of nitrogen for the second season's growth are reduced as nitrogen becomes available from the decomposing organic matter.

The results of the other tests harvested in the years 1950–1957 are shown in Table 6. Variable response is shown to applications of organic matter. In general, experiments on low humic and humic latosols with good physical properties show only small increases in yield. The heavier alluvial soils, the gray hydromorphic and dark magnesium clay soils, that have impeded drainage and poor physical properties, show larger yield responses to the applications of organic matter.

DISCUSSION

The gray hydromorphic and dark magnesium clay soils constitute approximately 14 per cent of the soils in sugar cane on the islands of Kauai and Oahu. These soils are extremely plastic and sticky when wet, and have low permeability. The addition to these soils of organic matter at rates of 15 to 30 tons per acre has resulted in marked improvement in their productive capacity. Where the soils were saline, the improved internal drainage resulted in the removal of excess salt. Where the soils were very slowly permeable, the organic matter additions resulted in better aggregation and aeration which, in turn, gave more extensive root systems and larger yields of cane and sugar.

These soils, as well as most others under cane culture, suffer structural deterioration by puddling and compaction caused by harvesting and other operations of heavy equipment which are practically continuous during the harvesting season, with only short delays even after heavy rains. Trouse (5, 6) covers the origin and treatment of soil compaction in the Hawaiian sugar industry. The use of organic materials has proved effective in reconditioning compacted and puddled soils. Figure 3a shows compacted soil two years after an attempt had been made by tillage operations to recondition an infield Tournahauler roadway at Waialua. Figure 3b shows soil from the same roadway two years after treatment with bagasse at the rate of 20 tons per acre. There is no question that the organic matter improved the tilth of the soil. One plantation, Olokele, spread bagasse on their infield roads concurrently with harvesting operations. This practice unquestionably minimized damage to the soils during adverse harvesting weather. How-

Figure 3. Above: Compacted soil two years after reconditioning Tournahauler roadway at Waialua Agricultural Company. Below: The same compacted roadway two years after treatment with bagasse at the rate of 20 tons per acre.

Figure 4. Soil improvement in the gray hydromorphic soils at Kekaha Sugar Company. At top left, composted trash is loaded for hauling to the field. Top right, the trash is dumped in the field prior to plowing. Center left, in seedbed preparation, the Storey plow is used following the operations of the Towner plow and the Howard rotary hoe. Center right, a close-up of the seedbed after trash has been incorporated. Below is shown the improvement in soil tilth two and one-half years after bagasse was incorporated at the rate of 15 tons per acre.

ever, as Olokele normally has good harvesting conditions during the late spring, summer and fall months, this practice was discontinued.

There are distinct advantages from the cultivation point of view for the addition of organic matter. The heavy clay soils are problem soils with respect to tillage. They are slow to dry and can be worked to optimum tilth only within a limited moisture range. If the purpose of cultivation is to increase the number and structural stability of aggregates with pores through which water and air move, then the addition of organic matter certainly enhances the accomplishment of the objectives of tillage.

Figure 5. At left, Pioneer Mill Company's trash-chopping unit at their cleaning plant. At right, spreading green chopped cane trash prior to plowing.

The addition of organic matter to the heavy clay soils results in a better distribution of irrigation water. Since more and more fertilizers are applied in irrigation water, uniform distribution becomes increasingly desirable. Evenness of cane growth down the full length of irrigated furrows is desired. Poor distribution of water and fertilizer results in uneven stands of cane. When the crop has grown to maturity, the wetter areas will be harder to dry out, even if the ripening period is so prolonged that it causes severe damage in the dry spots. Organic matter has proved effective in improving aeration, drainage and water-holding capacity in these dry spots, resulting in more uniform cane growth and ripening.

Cane trash and bagasse are generally composted from six to 24 months prior to incorporation in the soil (Figure 4). Pioneer and Kekaha have installed trash-chopping plants at their mills (Figure 5), and their three years of experience have proved that it is feasible to haul green chopped trash directly to the fields being plowed. This eliminates double handling and makes it possible to treat those sections of fields where the need is greatest without postponing plowing operations too long.

The largest acreages of soils improved in recent years by additions of organic matter are at Kekaha, Ewa, Lihue and Pioneer Mill companies. Smaller acreages

have received the trash treatment at Olokele, Grove Farm, Kilauea, Waimea, Kahuku, Oahu Sugar, Waialua, Wailuku, HC&S and Hilo Sugar companies.

Experience at Kekaha and other plantations within the industry has shown that, with the incorporation of organic materials, the physical properties of the heavy clay soils are so altered that they are no longer bottlenecks of production, and increased yields of cane and sugar result. This effective soil conditioning results in more vigorous root systems which will in themselves extend the duration of the improvement. Yield increases may be expected over a crop cycle of from six to eight years, which is more than adequate to pay the cost of soil improvement.

SUMMARY

Results of experiments and field yield data show that increases up to three tons of sugar per acre may be expected to result from the incorporation of 15 to 30 tons of cane trash or bagasse into the heavy clay soils.

The organic-matter additions result in improved aeration and drainage characteristics which in turn encourage better root systems. The duration of the improvement is set at a minimum of six to eight years, and has been observed to last as long as 18 years.

The addition of trash and bagasse speeds up the reconditioning of compacted and puddled soil and reduces the damage done by equipment during harvesting and other operations.

Stockpiling of the cane trash and excess bagasse for six months is recommended in the wetter districts and for 18 to 24 months in the drier districts, to permit the initial stages of decomposition to take place prior to incorporation in the soil. The stockpiled organic matter is incorporated without difficulty by presently-used tillage equipment. To eliminate double handling, chopped green trash may be hauled directly to the fields being plowed.

The cost of applying 15 to 30 tons of organic matter per acre has been estimated at $30 to $40. This cost is usually written off by increased yields in the plant crop.

LITERATURE CITED

1. Cline, M. G., 1946. Soil survey report of Hawaii. Unpublished
2. Ewart, G. Y., 1951. Reclamation and soil improvement at Kekaha Sugar Company, Limited, Rpts. Haw. Sugar Tech., pp. 75–79
3. Ewart, G. Y., 1951. Use of aromatic solvents in aquatic weed and pest control, Agric. Engr. Vol. 32(3), pp. 157–158, 160
4. Ewart, G. Y., 1952. Soil management in Kekaha, Rpts. Haw. Sugar Tech., pp. 26-30
5. Trouse, A. C., 1951. Origin and treatment of soil compaction, Repts. Haw. Sugar Tech., pp. 67–69
6. Trouse, A. C., 1952. Tillage evaluation, Rpts. Haw. Sugar Tech., pp. 10–13

IRRIGATION INTERVAL CONTROL IN THE HAWAIIAN SUGAR INDUSTRY

A. H. CORNELISON AND R. P. HUMBERT*

In 1950, studies were initiated to define more clearly the water requirements for optimum yields of sugar cane, and to evaluate the ability of various instruments to effect better irrigation control under the diverse ecological conditions in Hawaii. Irrigation studies were resumed to counteract the belief in a static energy-moisture reservoir, and to substitute a dynamic free-energy-moisture concept.

Sugar cane is a two-year crop in Hawaii, and plant and ratoon crops are started during all seasons of the year. Variations in weather are a cause of considerable variability in growth rates, sugar storage, flowering and tillering incidence. The temperatures in many areas during the cooler months of fall, winter and spring are close to minimum threshold values for vegetative top growth and root proliferation. This is of great importance in considering moisture uptake by the root system in a given climatic zone.

The physical characteristics of soils must be considered in the practical application of irrigation control. Moisture tension characteristics were determined for the principal irrigated soils (5), using Richards (10) pressure chambers. Two of these were equipped with ceramic plates for the low pressure ranges up to 15 pounds per square inch, and 10 others were used for pressures from 15 to 225 pounds per square inch, using cellulose membranes. A tension curve is completed in about six weeks, with entries at ⅓, 1, 2, 4, 8 and 15 atmospheres. These curves form the basis for scientific irrigation control.

BOUYOUCOS BLOCKS

The original work evaluating Bouyoucos plaster of Paris blocks was done by Swezey and Penhallow (11) at Ewa Plantation Company in 1941. Saline irrigation water, high shrinkage of the montmorillonite clay in the gray hydromorphic soils with which they worked, and measuring-bridge troubles caused erratic results, and the work was dropped. A re-evaluation of their data, using the concept of free-energy relations, shows that although their findings were accurate their interpretations were questionable.

The study of Bouyoucos blocks, along with tensiometers and other methods of soil moisture measurement, was resumed about 1947 by Ewart (6) at Kekaha Sugar Company, Ltd. As Bouyoucos blocks showed promise, an irrigation control program was developed at Kekaha which has proved to be an outstanding contribution.

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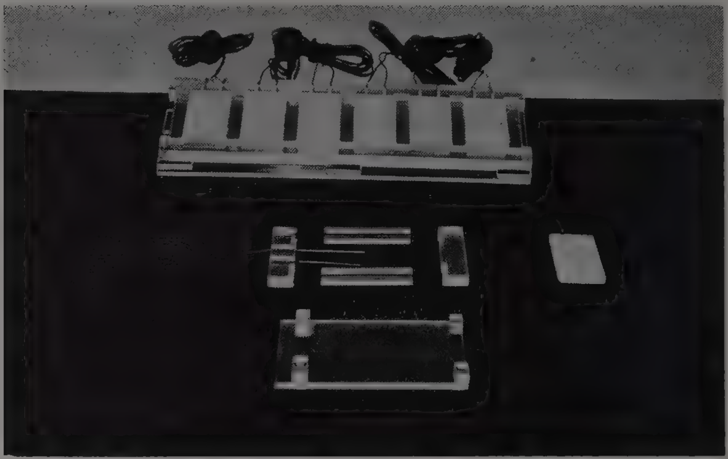


Figure 1. Lucite mold for Bouyoucos block manufacture. Note straight electrodes used from 1950 to 1956.

Studies at the Experiment Station, HSPA, corroborated these early findings, and an effort was made to determine why some blocks were erratic. After two and one-half years, during which 32,000 blocks were manufactured and tested, the picture of their operation became clearer. They proved to be definitely reliable when properly made, installed and used in the field.

Manufacture of Blocks

The first molds for the plastic units were made of paraffin-impregnated oak. Trouble in freeing blocks from molds made of metal and wood stimulated a search for other more suitable materials. Lucite, a hydrophobic, easily worked material that takes a high polish, proved to be most satisfactory (Figures 1, 2).

It was found that rubber-covered lead wires to the blocks lasted less than six months. The synthetics, polyethylene or polyvinyl, are currently being used. These materials have sustained so little damage that after years of exposure the wires recovered from the field are in almost new condition and can be reused.

Single wire electrodes of No. 19-2 Okophone were used from 1950 to 1956. This wire has a reasonable rigidity and can be rapidly stripped and straightened. The single wire electrodes pulled out of the blocks too readily. A hot-dip galvanizing was tried using solder, pure tin, and finally a eutectic alloy. A mixture of tin, lead and antimony that gives good chemical stability and "tooth" was selected. The liquid alloy acts as a solder base and the crystals included in it put a tooth on the wire which keeps it from slipping within the cast block.

Many modifications of the Bouyoucos block were tried between 1953 and 1956 in an attempt to increase sensitivity in the wet range, to decrease block hysteresis in the field, to reduce stray current flow external to the block in wet soils, and to make the blocks more durable under wet conditions (1). On the hypothesis that the blocks would be more sensitive if pore size distribution in the soil and in the block were more nearly identical, many additions were made to the plaster.

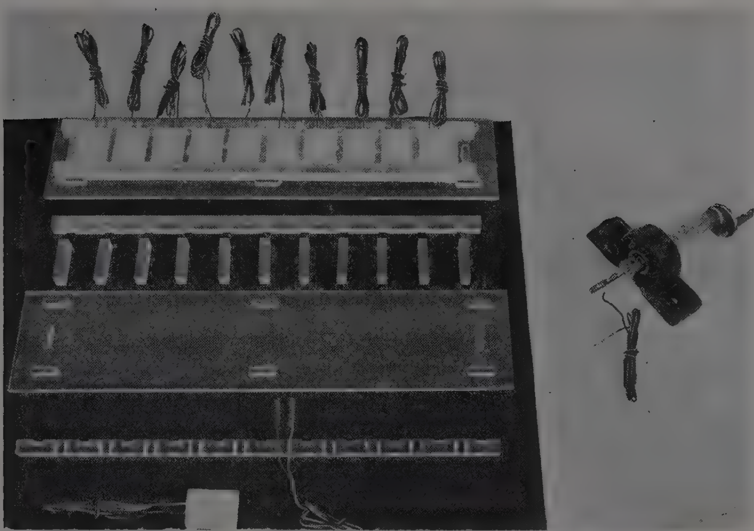


Figure 2. Helical coil electrode blocks showing electrode former, finished electrodes, the unassembled and assembled block molds.

Experiments were made with such materials as soil, sand, volcanic cinders, pumice, diatomaceous earth, and baking-powder-like substances for gas evolution. Most of the additives tended to speed up dissolution of the block without any significant increase in sensitivity. Use of dental investments, Duroc, Castone, and others, yielded similar results. Plaster of Paris without additives is still the preferred material.

Since no satisfactory means were found to modify pore relations in the block and water delivery rates from block to soil under the drying cycle tension gradient, the size of the block was reduced, thereby reducing the total amount of water lost before conductivity would be affected. In the reduction of the block size, it was desirable to keep the electrode area as large as feasible to avoid effects of surface contact variability. It was natural to turn to helical-shaped electrodes to attain this end. Six and one-half inches of bare Okophone #19 wire, wound on a ⅛-inch core at 10 turns to the inch, yielded a compact, self-hardened electrode suitable for a block of smaller dimensions (1.7 x 1.25 x 0.6 in.) (Figure 2). Under test in the field, these blocks gave much more stable readings, showed less over-all variability in construction, and gave quicker response to moisture tension changes. Little time was lost in changing to these smaller blocks on many plantations.

To increase the durability of the smaller blocks, the nylon treatment described by Bouyoucos (2) was tried. It added nothing to the life of the block in Hawaiian soils and actually appeared to decrease sensitivity to a certain degree. Since our blocks are used for one two-year crop only and are replaced in the following crop by new installations, the nylon treatment was dispensed with as uneconomic for standard practice. With electrodes placed in a rectangular, thin cross-section block, the shape would of necessity induce current flow lines exterior to the block when the soil was wet or when the block was placed in water. Reading of blocks in

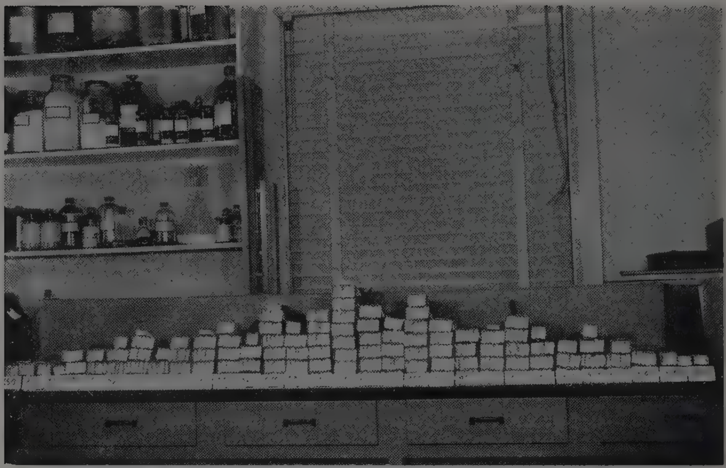


Figure 3. Frequency distribution of base readings in ohms for calibrated Bouyoucos blocks.

and out of water will also point out the change in resistance value associated with conditions exterior to the block.

Cylindrical blocks were made, using stainless steel 18-8 woven mesh concentric cylindrical electrodes imbedded in Duroc, Castone, and plaster of Paris. As was to be expected with concentric electrodes, there was absolutely no exterior current flow in these blocks. Readings were stable regardless of where the blocks were placed or how they were handled. They were hard to make, and cost about a dollar each to fabricate by hand. In spite of the poor volume-to-surface area relationship inherent in a cylinder, they were as sensitive to changes in moisture tension in the field as the rectangular blocks. However, with a cost differential of five to one against them, they were never recommended to displace the small rectangular block. The concentric electrode, however, might be developed for factory production and certainly warrants further study.

Temperature effects on block readings were covered by Bouyoucos and Mick in their first paper (2). In Hawaii, the soil temperatures at block depth are diurnally very stable and change very slowly upward or downward, largely dependent on time of year. Changes of 50 to 100 ohms, up one day, down the next, were noted in wet blocks, which were hard to explain and which caused considerable confusion when plantation personnel first encountered them while taking consecutive daily readings. It was discovered that if the bridge was kept insulated and at constant temperature, these ups and downs in reading did not occur. It was found that the standard resistors in the bridge have non-linear temperature coefficient characteristics such as manganin-wound resistors have, and, therefore, do not give constant readings when the bridge is used at different temperatures. An inquiry to the manufacturers brought out the fact that use of the manganin resistors would substantially increase the cost of the bridge. Temperature variation of the resistors in the bridge, rather than temperature variation

Figure 4. Recording station, easily accessible from road. Kekaha Sugar Company.

of the blocks in the soil, is the principal cause of the day-to-day variance in block readings so commonly experienced.

With the bridge insulated, small consistent increases in block resistance can be detected as much as five days before the large logarithmic changes occur as moisture tensions approach 0.8 to 1 atmosphere in the soil.

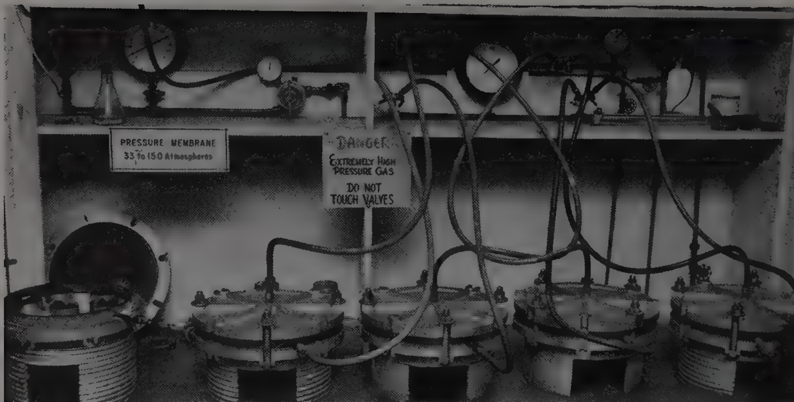
For several years the plaster of Paris used by the plantations was U.S. Navy "Pure Calcined Gypsum" purchased from salvage companies. This supply has now been exhausted, and U.S. Gypsum No. 1 plaster of Paris and orthopedic plaster of Paris are being used.

The blocks are made by mixing pure plaster of Paris with water in the ratio of two to one. The fresh mix has the consistency of thick mayonnaise, and is adjusted to set in 20 minutes so that two gangmolds will keep a man fully occupied in a cycle of setting up, casting, removing, cleaning and resetting.

With the coiled electrodes properly spaced in the mold, the plastic mix is poured, and settled by horizontal shaking to remove air trapped in the mix and in corners of the mold. The excess mix is rapidly leveled off with a spatula; several more horizontal shakes give a smooth top surface to the cast and the mold is set aside to harden.

After drying, the mold is broken apart to remove the blocks which are allowed to air-dry for several days. Then four cycles of wetting and air-drying are performed to pre-age and stabilize the blocks and to establish stable electrode contacts. Recrystallization takes place during this period. Four cycles over a period of a month cure the blocks sufficiently for saturated calibration in the laboratory.

Under mass production, the frequency curve of base resistance readings shown in Figure 3 is obtained. Blocks with base readings above 550 and below 300 ohms are discarded. Only blocks with similar base readings are installed in a given field. This speeds up reading and assures picking up any trends in development of soil



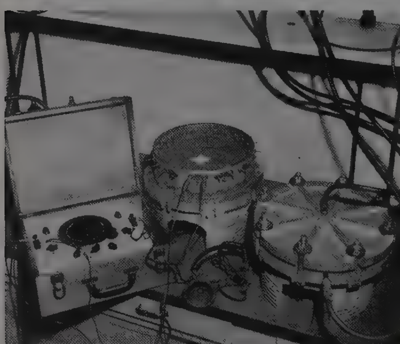


Figure 5. Above: Soil moisture tension determination chambers used in determining retention properties of Hawaiian soils. Below: Tension chamber with wall-penetrating leads for Bouyoucos block calibration.

moisture tension gradients. It should be noted that the base reading in saturated soil is slightly different from that in distilled water, but this is of little consequence in irrigation interval control.

Meters for Reading Resistance

The Bouyoucos Wheatstone bridge has proved to be the most accurate, stable and durable of all the commercial units tested. It is designed to read resistance with long leads so that roadside readings of infield stations are possible (Figure 4).

Use of Blocks for Interval Control

Early work indicated that the block resistance readings were influenced by soil properties. Accordingly, studies were initiated to calibrate the blocks at a given moisture-tension reading by use of a modified Richards chamber with wall-penetrating leads for the blocks (Figures 5a, b). Readings were taken as the soils reached tension equilibrium at the different levels desired. This program led to the identification of the critical zone in the moisture-tension curve where growth is retarded. These critical zones in terms of ohms resistance were checked against the spindle elongation technique as described by Ching (3). Figure 6 shows typical relationships of spindle elongation to resistance readings obtained at Oahu Sugar

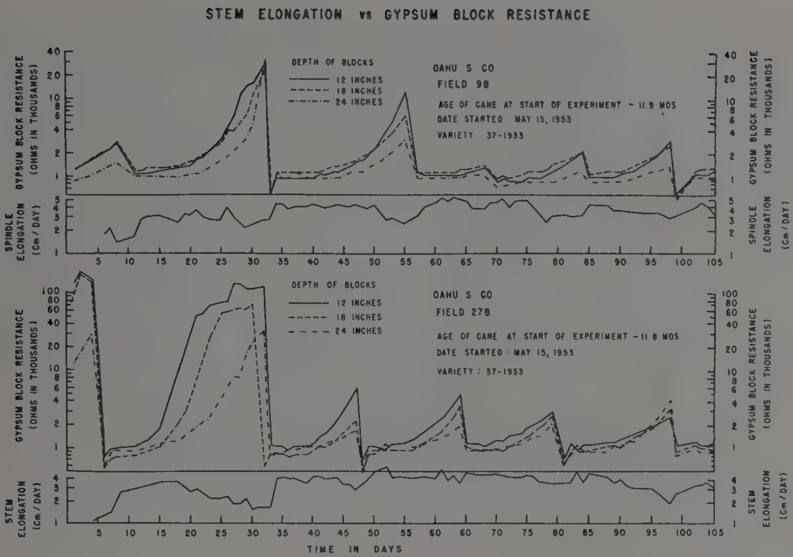


Figure 6.

Company in two soil types. This method gives an accurate tension-resistance-moisture-percentage relationship to physiological behavior. Data shown in Figure 7 indicate the relationships between available moisture, moisture tension, and resistance on three principal soils of the irrigated districts. When irrigation is applied at four atmospheres tension and at approximately 5,000 ohms, plants will have used up approximately 53 per cent of the available moisture at the point of measurement held between the moisture equivalent and the permanent wilting percentage for the gray hydromorphic clay soil; approximately 67 per cent for the low humic latosol; and 78 per cent for the humid ferruginous latosol. A safety factor of two or three days additional drying time was selected and the corresponding resistance reading was established as the point at which the next round of irrigation was to be scheduled.

The successful use of blocks depends to a large degree on their placement in the soil mass under the plant. They should be installed under representative stools at two-thirds the depth of the zone of maximum root concentration (Figure 8). This position was selected since above this region depletion of water in the soil is most rapid. Contrary to many claims, moisture is not uniformly removed from all depths of soil within the root zone. Moisture depletion is most rapid at the surface, decreasing with depth to the field capacity at the soil horizon just below the deepest roots. This range is found in restricted rooting zones nine inches deep, or it may exist in a zone expanding to four feet or more in depth, dependent entirely upon depth and density of root proliferation. In soils of steep tension gradient with depth, i.e., shallow soils, the placement of the moisture measuring instruments is of prime importance. Profile placement of blocks in "Christmas Tree" arrangements at several depths is recommended in new loca-

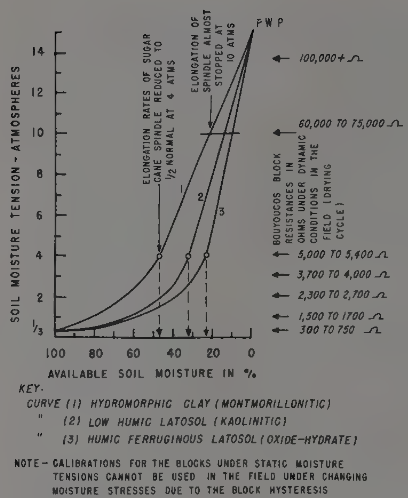


Figure 7. General relationship between Bouyoucos block resistance, moisture tension, and moisture per cent, in three typical Hawaiian soil families under dynamic conditions in the field.

tions to establish moisture-tension gradients with depth with age of crop, to check the depth of infiltration of applied water, and to study increased depth of rooting encouraged by proper timing of irrigation (Figure 9). For example, over-irrigation saturates the lower horizons, and the depth of effective rooting is restricted by inadequate supplies of oxygen (7). Moderate moisture stress in the upper horizons results in better aeration and encourages roots to proliferate into the lower horizons. Deeper rooting through proper subsoil fertilization and proper irrigation management can only result in higher yields of cane and sugar. In many of our irrigated lands the depth of tillage is believed to be inadequate, so that the seedpieces are often placed on hard soles of unknown longevity, while the tilled soil has been piled into levees to contain the irrigation water. Root pattern studies should be conducted before the blocks are installed, since reports by Lee and Weller (9), Yamasaki (13) and Humbert (8) show that rooting patterns are extremely variable depending on moisture supply, aeration, profile characteristics and soil compaction.

Restricted rooting is inevitable wherever poor moisture infiltration has persisted. It also occurs where water is applied too frequently and where anaerobic conditions kill the more deeply penetrating roots. Heavy losses are experienced during the ripening period prior to harvest and also during mechanical harvesting, since shallow rooting results in heavy stalk mortality and many stools are uprooted in the mechanical harvesting operations.

Assuming relatively uniform soil conditions in a field of 100 acres, a minimum of four stations of three Bouyoucos blocks each will suffice for adequate control. Each block is placed under a normal-sized stool several furrows away from any other block. Wire leads are attached and taken to the field road where they are properly identified (Figure 4). Station 1 is located in normal soil in the first section irrigated with each round, Station 2 in the wettest area, Station 3 in the driest area, and Station 4 in normal soil in the last area irrigated.

Figure 8. Correct position of Bouyoucos block in relation to root system. Kekaha Sugar Company.

Stations 2 and 3 give extremes of conditions in the field; the average of all four will give a mean value for the field. Stations 1 and 4 bring into the picture the "time" factor involved in applying water to the entire field, varying from several days to a week or more depending upon labor, water supply and field size. If this time factor for water application is not considered as important as instrumentation, no control system will operate properly on large acreages for any lengthy period. A cyclic time-scheduling of water and labor to each field, so that the field falls into a time and space pattern, is an inherent requirement of a control system; otherwise an impossible situation of having to irrigate all fields at once is sure to arise after a heavy uniform rainfall covers the plantation. To reinstate the cycle, water must be applied to some of the fields too soon by any standard of measurement, and possibly to other areas too late if the total area is large and the water supply small. The succeeding irrigation rounds are applied as the fields dry out in the sequence established. A degree of elasticity in handling water and manpower is desirable since crops of different ages have different water requirements, and irrigation schedules are constantly being changed, particularly during "ripening" periods. Soil moisture data are extremely useful in determining priority of irrigation needs. Kekaha Sugar Company irrigates saline fields at higher moisture levels than non-saline soils to offset the osmotic pressure and to prevent accumulation of salts at the soil surface. This plantation uses indices of 2,000 to 3,000, instead of 5,000 ohms, for their saline soils.

Status of Bouyoucos Block Control as of December 31, 1957

Bouyoucos blocks were being used on 41,686 acres on eight irrigated plantations. Additional acreages on these plantations were being irrigated by use of data from blocks installed in adjacent control fields.

Figure 9. Bouyoucos blocks installed at several depths and at variable distances from stool in checking water removal in relation to rooting characteristics.

TENSIOMETERS

The first experiments with the porous ceramic tensiometer were made by R. J. Borden and Rockwell Smith in the 1930's, using an English-made unit. H. F. Clements (4) employed tensiometers for controlling irrigation in his crop log studies at the HSPA Waipio Substation in 1947. In the last 10 years, tensiometers have been tried on many plantations, and are presently in use at Hawaiian Commercial and Sugar Company.

Many workers have found them accurate in the range of moisture tensions below 0.8 atmosphere. The authors' studies corroborate their accuracy in this tension range. To be effective in indicating when the next irrigation should be applied, the porous cup must be installed below the zone of maximum concentration of roots, thereby being placed below the zone from which the bulk of the water is extracted. What is happening at different levels above and in different soil horizons in the root mass can be inferred from the readings at the deep level. High stress can be obtained in the upper horizons with a shallow-rooted crop without materially changing the soil moisture levels at greater depths.

Figure 10. Installation of irrometer in cane two months of age, placed ⅔ of the length of the line from the head of the furrow. Placement at 18-inch depth in four-inch soil auger bore. HC&S Company.

Figure 11. Daily reading of irrometer for scheduling irrigation. HC&S Company.

The tensiometer (irrometer) is used to schedule irrigation on approximately 27,000 acres at HC&S Company (12). The instruments are placed in every field at depths of 18 to 24 inches, two-thirds of the way down the line in an area of the field where the irrigation rounds start (Figure 10). If there are two or more soil types in a field an irrometer is placed in each.

The irrometers are read daily (Figure 11) by the subdivision overseers and recorded by the Irrigation Department. The readings are plotted on a graph and, by projecting the shape of the curve, the desired irrigation interval is predicted. The irrometers are serviced and read *in situ*, in the interior of the fields.

In soils with high swelling and shrinkage, the irrometers are often "jacked" out of their original position and so loosened that the moisture films are broken and the instrument becomes inoperative. Maintenance costs were high with the older models when approximately four man-hours each day were needed to keep them in shape (12). The new models of polyvinyl plastic cost much less to maintain (Figure 12).

Figure 12. Calibration of irrometer gauges. Checks are made against master gauge closest to vacuum pump. Five gauges are calibrated at one time. HC&S Company.

The irrometers are removed from the fields approximately seven months before harvest when the field goes on ripening schedule. Irrigation intervals are lengthened, and since the soils dry out beyond the limit of the instrument, the irrigation interval is scheduled by sheath moisture data. The use of irrometers is warranted in sandy soils, or soils that behave as sands, where a large percentage of the available moisture is held in the low tension range.

SUMMARY AND CONCLUSIONS

Accurate definition of the time to apply supplementary water is of prime importance in realizing economies both in water and in cost of sugar production. The requirements for attaining accurate definition are knowledge of the moisture retention and intake properties of the soils, the moisture status of the soil, the effect of water at different stages in the life of the cane plant, the water resources and distribution systems available, together with the ability to coordinate these factors into an operating entity.

Soil moisture retention and intake rates are obtainable by direct, fairly accurate, physical measurements. Water resources and distribution systems are known entities. The effects of water on production of cane and sugar are obtained by experiments. The remaining factor, soil moisture status in relation to time, while appearing simple, is in actuality the attempt to evaluate a changing force field in a non-homogeneous system. As such, its evaluation is subject to statistical, technical, and human error, and hence should never be considered an absolute value. This assumption has led to arguments as to the best measuring instrument, the placement of the instrument, the number to use per area, etc. In line with this

philosophy, it becomes apparent that any instrument of sound physical design, which is capable of measuring a time point value in a changing gradient system or force field, can be used, since the slope of the gradient and the extent of the force field have to be inferred in any case and related to their effect in the final analysis.

On this premise, the cheapest instrument which can meet both the statistical requirements for accuracy and the economic requirements for large scale application, and which does not greatly influence the system it is attempting to measure, would be recommendable for commercial application. The evaluations of the Bouyoucos plaster of Paris resistance blocks and the irrometer-tensiometer types of instrument have been carried out under Hawaiian ecological conditions. They have been found adaptable thereto, and have been successfully applied on a large scale in the irrigation of sugar cane. Either or both of the instruments discussed are reasonably adequate for estimating the proper time for irrigation on a commercial scale.

LITERATURE CITED

1. Bourget, S. J., D. E. Elrick and C. B. Tanner. 1958. Electrical resistance units for moisture measurements: their moisture hysteresis, uniformity and sensitivity. Soil Sci. Vol. 86, No. 6, pp. 298–304.
2. Bouyoucos, G. J. and A. H. Mick. 1940. An electrical resistance method for the continuous measurement of soil moisture under field conditions. Mich. Agr. Expt. Sta. Bull. 172.
3. Ching, A. Y. 1930. A comparison of the residual moisture at the point of cessation of growth of sugar cane with the wilting coefficient of other plants (unpublished).
4. Clements, H. F. 1952. Factors affecting the growth of sugarcane. Haw. Agr. Expt. Sta. Bull. No. 18.
5. Cornelison, A. H. 1954. Some moisture tension characteristics of Hawaiian soils. Haw'n Planters' Rec. Vol. LIV, pp. 205–209.
6. Ewart, G. Y. 1949. Materials and methods for large scale irrigation interval control. Haw'n Sugar Tech. Vol. 8, pp. 6–14.
7. Humbert, R. P. 1954. Water distribution studies in the Hawaiian sugar industry. Haw'n Planters' Rec. Vol. LIV, pp. 211–225.
8. ———— 1959. Soil as a factor in varietal yield decline. Proc. 10th Congress ISSCT (in press).
9. Lee, H. A. and D. M. Weller. 1927. The progress of sugar cane roots in the soil at different ages. Assn. Haw'n Sugar Tech. pp. 69–72.
10. Richards, L. A. 1941. Soil Science Vol. 51 pp. 377–386.
    1943. Soil Science Vol. 56 pp. 332–333.
    1944. Soil Science Vol. 57 pp. 119–121.
11. Swezey, J. A. and H. C. Penhallow. 1942. Letter to G. J. Bouyoucos dated November 11, 1942.
12. Waterhouse, A. D. 1951. Irrigation control at Hawaiian Commercial & Sugar Co., Ltd. Haw'n Sugar Tech. Vol. 10, pp. 37–41.
13. Yamasaki, Y. 1956. Root system development under different soil improvement and cultivation practices for the main soil groups. Haw'n Sugar Tech. Vol. 15, pp. 10–12.

LOSSES FROM WET WEATHER HARVESTING

R. P. Humbert and John H. Payne*

It has long been recognized that harvesting during wet weather results in substantial losses of sugar to the Hawaiian industry. Mechanization of harvesting operations has increased the losses from wet weather harvesting by increasing the quantity of extraneous material which must be handled both in transport and in the factory. Other substantial effects are perhaps less evident.

Sucrose-Reducing Sugars Ratio

The industry has used a variety of preharvest sampling procedures and ripening logs to establish harvesting schedules. Borden (1), in his studies of the nitrogen effects upon the yield and composition of sugar cane, proposed the use of the sucrose-reducing-sugars ratio as an index of maturity. Preliminary examinations were promising and studies have continued over the last 10 years.

The analysis of the immature portions of the cane stalk continues to show promise as an index to maturity. Table 1 gives an analysis of 8-10 stalk preharvest samples of all 37-1933 fields at Lihue Plantation for 1955.

It is obvious from these data that the low-yielding fields were relatively immature and had a high percentage of reducing sugars not yet converted to sucrose.

Preharvest samples of 8-10 stalks from fields logged for the 1955 and 1956 crops at Olaa Sugar Company showed a relationship between the sucrose-reducing-sugars ratio and juice quality (Figure 1).

The data indicate a marked improvement in juice quality as the sucrose-reducing-sugars ratio increases to four. Above four, there appears to be little additional improvement in juice quality.

Studies at Hamakua Mill Company have been continuous, starting with the 1955 crop. The correlations of the sucrose-reducing-sugars ratio and juice quality

TABLE 1. RELATION OF SUCROSE-REDUCING SUGARS RATIO IN 8-10 STALK PREHARVEST SAMPLES WITH YIELD

Field Yields	Reducing Sugars	Sucrose	S/RS	TC/TS
	%	%		
< 7 TSA	11.8	37.5	3.2	10.62
7–10 TSA	6.4	41.7	6.5	9.64
10–13 TSA	5.7	46.2	8.1	7.13

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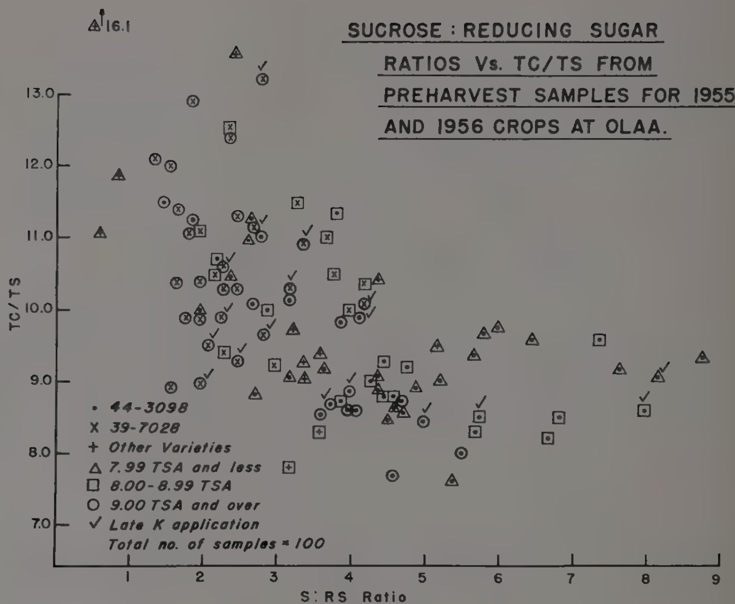

Figure 1.

were excellent for the 1955 crop which was harvested during a dry year. However, during 1956 and 1957, rainfall at harvest obscured all relationships between nutrient ratios, moisture, and sucrose-reducing-sugars ratios with juice quality. Generally speaking, when rains fell in excess of 0.3 inch per day on the average, the tons of cane required to produce a ton of sugar increased significantly.

Rainfall and Quality of Burns

Light rains and showers do not usually affect the quality ratios unless they occur just before the cane fields are burned. If showers occur immediately prior to the firing, the burns are poorer than normal and more of the trash in the blanket of cane is hauled to the mill. This extraneous material is not only costly to transport but reduces the efficiency of the factory.

This is manifest in many phases of the manufacturing process. In the first place, the cane cleaning plants must be designed to handle a much greater tonnage, which increases the capital investment. Secondly, more fibrous trash enters the mill, which not only reduces the extraction but also decreases the capacity of the mill. Additional soil, grit, and rocks produce extra wear on the mill rolls, conveyors, pumps, and pipes, thus greatly increasing maintenance costs. Clarification problems increase, necessitating capital expenditures to enlarge the capacity of the clarification station. The trash causes lower juice purities, decreasing over-all recovery and increasing the quantity of low-grade material to be handled. Finally, the trash and soil, by adversely affecting the quality of the sugar, increase refinery costs.

The monetary losses caused by each of these individual items are highly

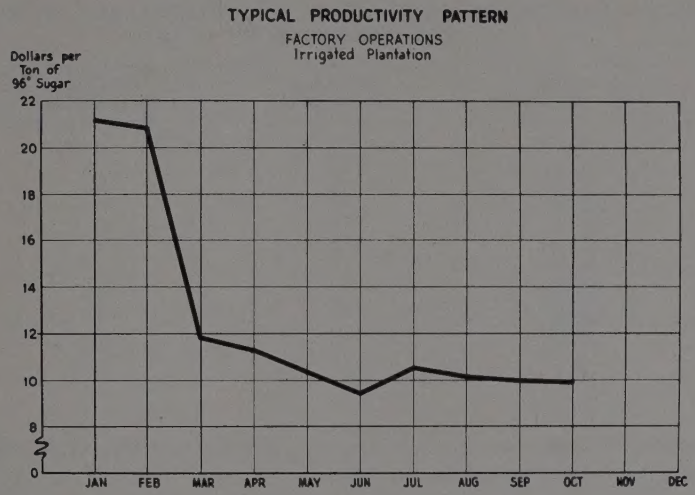

Figure 2. Factory costs per ton of sugar for a typical irrigated plantation.

variable from factory to factory and from week to week. Some generalizations will fix the order of magnitude, however. Ten per cent fibrous trash mill on net cane will cause about 1.5 per cent decrease in extraction if the grinding rate is kept approximately the same. Data in which the attempt was made to keep the extraction at a resonable figure showed that milling 10 per cent trash with the cane required a grinding rate reduction of about 16 per cent.

The decrease in juice purity averages close to 1.0 for 10 per cent trash milled. This means a reduced recovery of approximately 0.75 per cent.

These two items represent very substantial sums of money, and if the extra capital costs, maintenance costs, and refinery costs are added, the total is very large indeed. Figure 2 shows that the factory costs per ton of sugar for a typical irrigated plantation are much higher during the early months of the year when trash figures are high and milling operations are on a stop-and-go basis.

Soil Compaction and Puddling

Mechanical harvesting during wet weather causes serious losses in future crops. Compaction and puddling of soils result in losses up to three tons of sugar per acre in the infield roadways (2). Damage to the physical properties of the soils is often severe, and reconditioning is usually begun before the soils are dry enough so that the compacted clods can be shattered. Normally, the ratoon fields appear spotty, with the compacted and puddled soils remaining unproductive. Losses in sugar production due to compaction and puddling of soils are estimated at $400,000 annually.

Losses of Sugar Grown but not Recovered

Harvesting continues during rainy periods in many segments of the industry. It is recognized that harvesting must proceed when rains fall throughout the year as they did at Onomea Sugar Company in 1948, when there were only 40 rain-free days. However, rainfall records show that such extended periods of rainy weather

TABLE 2. RAINFALL DURING HARVEST AT HAMAKUA MILL CO. FOR 1958 AND 1959 CROPS

Average Daily Rainfall	1958 Crop No. of Fields	1959 Crop No. of Fields
In.		
0	2	14
.01–.09	8	12
.10–.19	9	13
.20–.29	3	7
.30–.39	6	3
.40–.49	5	5
.50–.59	3	6
.60–.69	0	2
.70–.79	1	0
.80–.89	2	1
.90–.99	0	0
1+	2	1

are unusual. An analysis of weather data should indicate within what period the harvesting operations should be confined.

Table 2 lists the fields that received varying amounts of rainfall during the harvesting of the 1958 and 1959 crops at Hamakua Mill Company.

In 1958, a strike year, when four of the best months for harvesting were lost, 46 per cent of the fields were harvested while an average of 0.3 or more inches of rain was falling. In 1959, a normal year, 28 per cent of the fields were harvested while an average of 0.3 or more inches of rain fell.

According to the Hamakua Mill Company data for 1959, an additional two tons of cane were required to make a ton of sugar in 28 per cent of the fields harvested. If the cane had been of the same quality as that harvested during dry periods, there would have been an increased sugar production of approximately 16 per cent. On an industry basis, this represents a substantial sum of money.

SUMMARY

Data from several plantations are presented to point out the usefulness of preharvest sampling techniques in establishing the order of fields for harvest. These data, when correlated with rainfall at harvest, show that substantial losses due to poor cane quality result from harvesting when the average daily rainfall exceeds 0.3 inch. These losses, coupled with an estimated $400,000 loss caused by compaction and puddling of soils during wet weather harvesting, as well as with increased costs of hauling, decreased milling rate, lower extraction, added maintenance costs and lower factory recovery, represent a significant reduction in income. It is recommended that additional effort be made to evaluate the advantages of increasing milling capacity, shortening grinding seasons, and suspending field work during periods of adverse weather.

LITERATURE CITED

1. Borden, R. J., 1948. Nitrogen Effects upon the Yield and Composition of Sugar Cane. Haw'n Planters' Record, Vol. LII, No. 1, pp. 1–51
2. Humbert, R. P., 1959. Soil as a Factor in Varietal Yield Decline. Proc. 10th Congress ISSCT (in press).

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